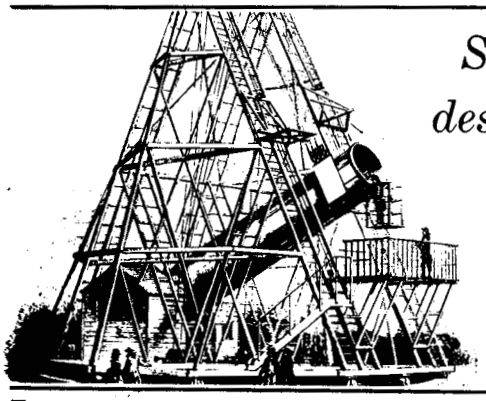
TELESCOPE MAKING 3

The magazine *for, by,* and *about* telescope makers!

Spring 1979



Sir William Herschel describes his historical 48-inch reflector

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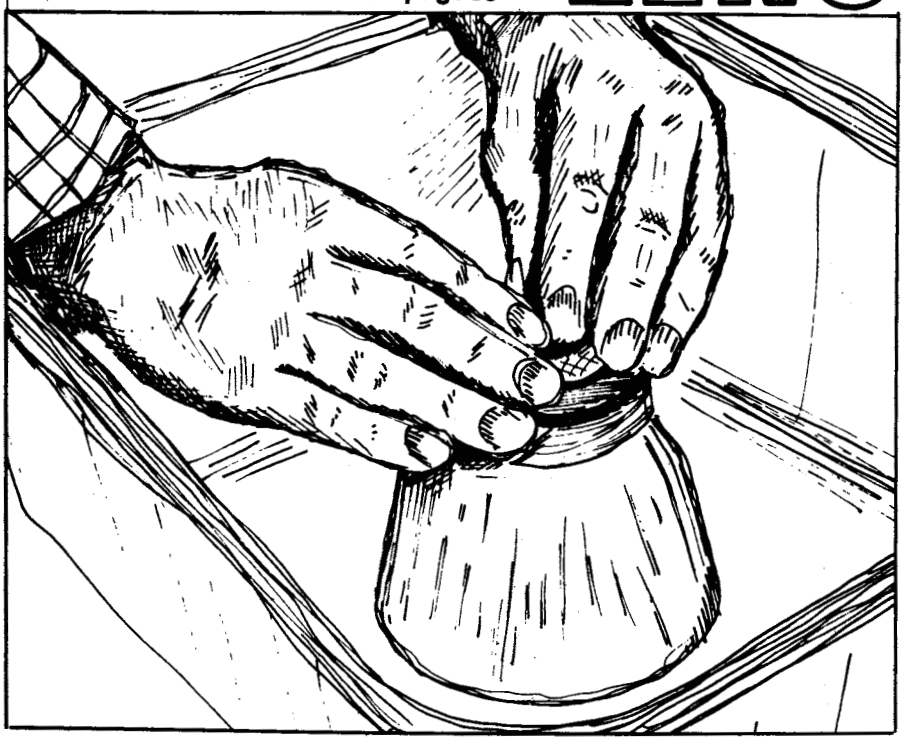
how to make a LENS

see page 35



BIG TELESCOPES

This issue of TM is devoted to Big Telescopes — telescopes over 12 inches in aperture. But as John Stull points out with the title of his article "Design of a Large 'Small' Telescope" (page 5), large is relative. But if the size of a telescope gets much over the size of a man, and begins to weigh twice, three times and more what a man weighs, that telescope is big. Suddenly, things that seemed easy with a small telescope are difficult. Moving the scope over a hundred yards or so to catch a glimpse of Mercury as it sets into a treeless section of the horizon (which you may remember from your small refractor/reflector days) is a hopeless task. Mercury goes down unobserved. Things like tube stiffness become a problem in engineering. You begin to worry about vandalism because you can't bring the scope inside.

Perhaps nothing brings headaches as much as the stories about little-bitty catadioptrics outperforming 16-inchers. "But," protests the owner, "there were 23 people in the dome and the seeing was bad and it was right after sundown. The mirror was still warm. Did you see M-13 with it after midnight when the crowd finally left?" It shows, however, that every aspect of design counts much, much more.

By the way, there will be more Big Telescope stories in the issues of TM that follow this one. TM2, which carried the announcement, went out rather late. Writers, in turn, didn't have enough time to prepare their stories. And as we go to press, there are more articles coming in....

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TELESCOPE MAKING

The magazine *for*, *by* and *about* telescope makers!

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This issue of TM wasn't intended to have 48 pages. It just worked out that way. I never thought there would be enough articles, enough pictures, enough good ideas coming in so quickly. Besides, those more experienced in the ways of publishing counseled me to "save it for the next issue." But what could I have left out?

I could have dropped the Jones-Bird catadioptric Newtonian, but it's a fascinating and challenging instrument. Telescopes of this basic design are already commercially available in Japan and Europe. Want to place any bets on when they'll appear in the U.S.?

Articles about observatories should appear in a Spring issue. After allowing adequate time for thinking, planning, and talking your spouse into it, any observatory project needs an early start.

The lens making article — now there's a big item. By holding it back a few issues I could have kept TM3 within its orignial page budget, but lens making know-how is an absolute necessity for anyone interested in making a relay telescope or a catadioptric Newtonian, not to mention refractors. It had to run also.

Herschel? Not in a million years! Herschel's qualifies as the biggest of the big amateur telescopes in this issue plus it's one of the most intriguing accounts I've ever read anywhere about making a telescope. And it's in Sir William's own words too.

The result is that TM3 really is 48 pages. If you like it, perhaps you'll be moved to "vote with your wallet" and extend your subscription now. That'll help because we'll know that TM enjoys support from its readership. As with any new magazine, we're a bit worried when the first batch of subscribers comes up for renewal. Older magazines don't have to worry because in general they can count on a steady fraction of renewals.

A solid vote of confidence from the readers could go a long way toward keeping TM this big every issue.

Sincerely,
Richard Berry

P.S. I plan to attend the Riverside Telescope Makers Conferencce in Riverside, California, May 26 through 28. I'm hoping I'll have a chance to meet many TM readers there.

Letters

Grinding Machines

Dear Sirs / I would like to inquire if you could send me plans for a grinding machine that uses ordinary vee-belt pulleys and components available at a Sears or good hardware store. I realize that machines have their problems and require attention when grinding, but when it comes to a 12" mirror, it's bound to be easier than by hand.

Gary Weseman
315 Los Arbolites
Oceanside, CA 92054

Dear Mr. Weseman / I'm calling for articles on the grinding, polishing, and testing of telescope mirrors for TM5. Machines for grinding and polishing are, of course, part of the topic. In the meantime, check the Scientific American ATM books for ideas, and see the articles in the following issues of **Sky and Telescope**: *11/52, 2/56, 8/57, 10/60, 5/64, 3/65, 12/70.*

—R.L.B.

Machinists

Dear Sir / I enjoy the new magazine TELESCOPE MAKING. I did have two questions though. First, in Mr. Lucek's letter on page 32 of TM2, in which he describes the properties of silicon nitride as a mirror substrate, I was surprised that you didn't make a comment about the thermal coefficient of expansion being 1000 times greater for this new material than it is for Pyrex. Needless to say, such a mirror could never keep its figure under normal use.

Second, I am wondering if ATMs have something against machinists? I know we are expensive to hire (I am one), but that does not mean only machinists have lathes. Surely there must be some hobbyists of an astronomical bent with lathes. I would like to see them encouraged to give their ideas on projects that do require machining — projects like drive gears, mounts, etc. Not all of us want to see how cheaply we can make a telescope, but how well. Thank you for hearing my questions.

Yours truly,
Murray McEwan
Box 127
Tisdale, Sask., Canada
S0E 1T0

Dear Mr. McEwan / Your comments on the silicon nitride material served to point out a horrible typographic error. The coefficient of expansion of silicon nitride is $3x10^{-6}$/°C, not 10^{-3} as printed. It's typos like that one that make me want to turn in my Editor's green eyeshade for a model railroading cap or maybe take up basket weaving!

Next, I would like to assure you that ATMs don't dislike machinists or finely-crafted telescopes. Bill Wyants's article, as well as others in TM2 (and this issue too), should serve to convince you of that.

However, as you point out, machining costs a lot if you buy it, or involves having, in one's network of friends, someone who happens to run a lathe in his basement. Sometimes getting parts machined can seem as difficult as going to the Moon.

Remember too, that the telescope making literature has been dominated by telescope builders with access to machine tools. And I'm sure that lots of potential TMs have been turned aside from building a telescope because, as far as they could tell, the lathe-in-the-basement was an absolute requirement.

So, when a fellow TM comes up with a decent, workable way of circumventing machining, he's probably justified in crowing about it. I think it helps everybody to see a great diversity of successful routes to making a fine telescope.

—R.L.B.

S.A.S.E.

S.A.S.E means "self-addressed stamped envelope". If you write to a *TM* author asking for more information or advice, we expect you to extend the courtesy of sending an S.A.S.E. along with your letter. Please understand that writing in *TM* places authors under no obligation to answer mail from readers -- though most are happy to do so. Please do your "homework" before writing and don't ask for information in the article or information you could find yourself with a little looking.

Prototype Builders Wanted

Would you like to build the prototype of a new design? We are looking for a skilled telescope maker to build a catadioptric Newtonian similar to the Jones-Bird instrument described in this issue. The completed instrument will be á photographic telescope of high quality. If you're interested, write to Robert Cox, 205 E. Elm St., O'Fallon, MO 63366.

TM4

Telescopes for Beginners

Design and build, if at all possible, a high-performance, low-cost telescope that any beginner could build. Keep the cost low, keep fabrication techniques simple, but maximize performance. Submit designs to *TM* by May 1, 1979, and we'll run as many as we can. The best will be written up in one of the fall issues of ASTRONOMY.

TM5

Telescope Mirrors

Grinding, polishing, and testing telescope mirrors is the topic for *TM5*. Every aspect -- from tips that save time, fancy methods for testing, grinding machines, how to make focograms, group projects for instructing mirror-making -- if it's about making mirrors, it's for *TM5*.

Cassegrain Formulae

Dear Sirs / With regard to the article by Richard Buchroeder in TM1, an error in equation (7a) seems to have escaped the errata notice in TM2.

As originally presented in TM1, the equation substitutes "p" (prime focus intercept distance) for the "m" (secondary magnification) that should appear in the equation according to equation (7).

I very much enjoyed this article about Cassegrain optical systems. I hope to someday get the resources together to make a large telescope, perhaps even a Ritchey-

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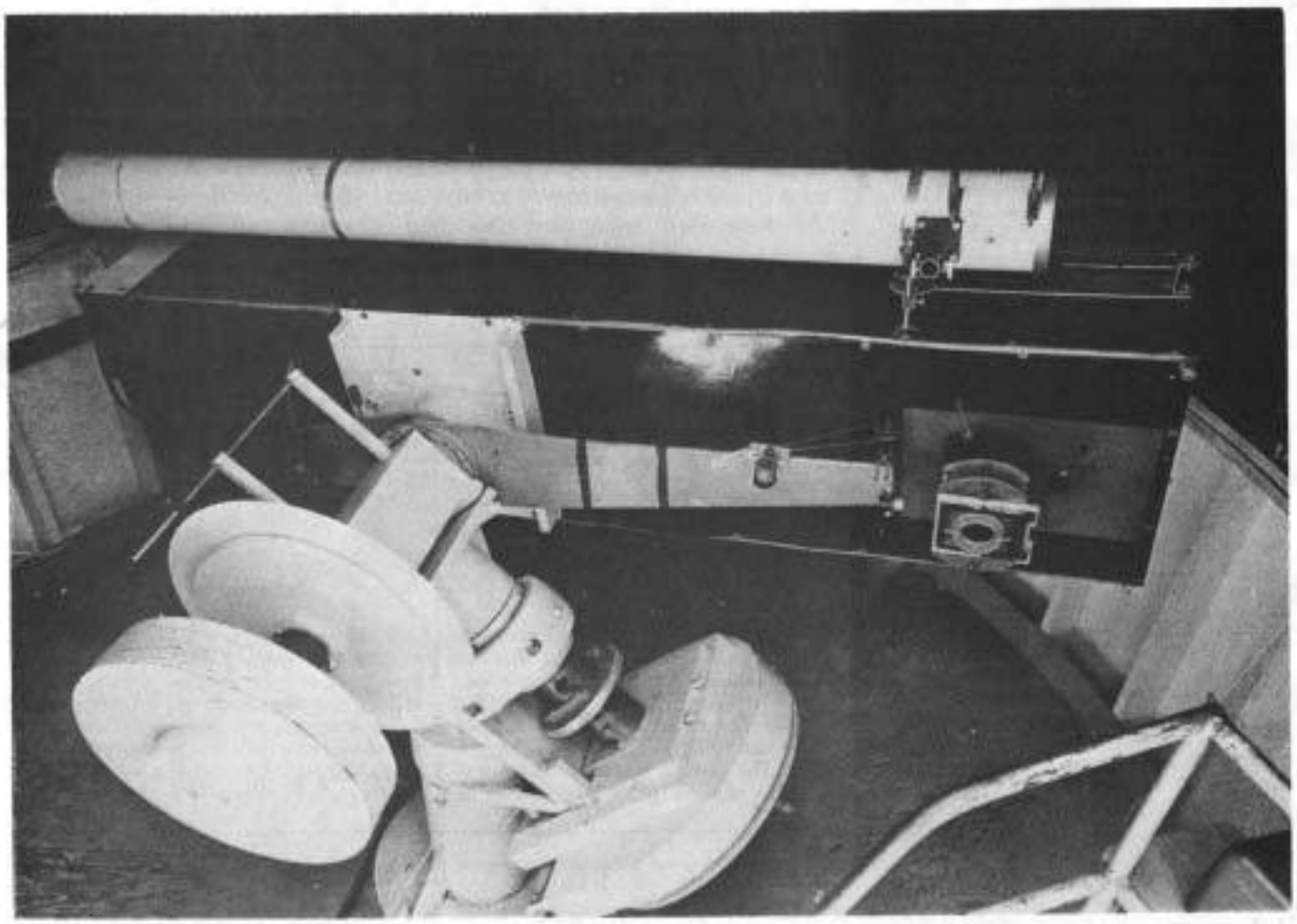
Design of a Large



In the last few years I have designed and constructed for the Alfred University Observatory two Newtonians which are "large" by the criteria of this issue of TM. They are a 20" f/5.5 (completed in 1971) and a 14¼" f/6 (completed in 1976). My only previous experience at telescope design had been a complete new mount and tube for a 9" f/13 Fitz refractor objective which had been salvaged from an instrument installed in the original observatory in 1863. I started from complete ignorance, and so the 20" and 14¼" represent stages 2 and 3 of what I hope is my progress in telescope design. There are features of both these instruments that I would change the next time out, and I will indicate them as I go along.

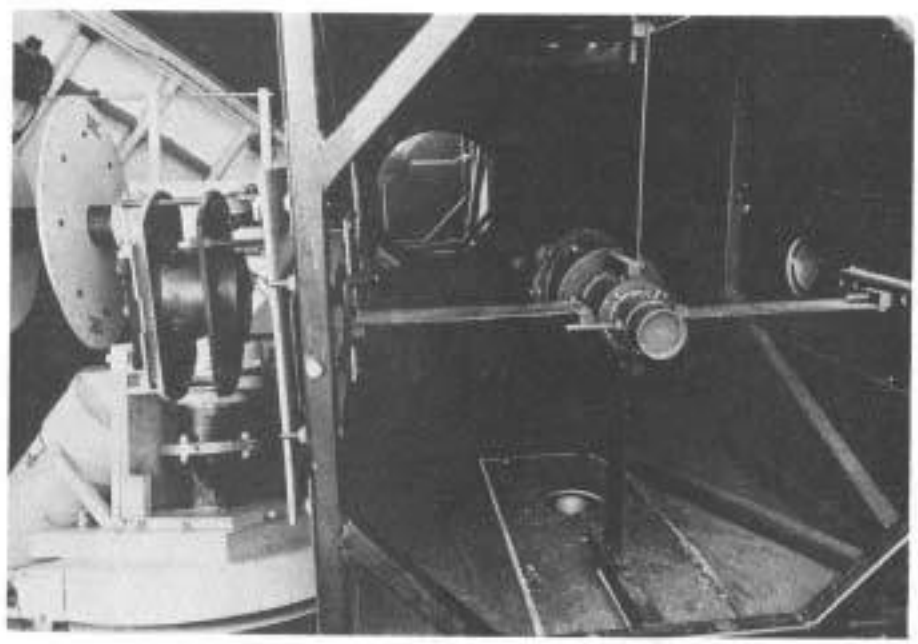
The combination of rigidity and low cost which were the criteria for these instruments dictated that they be homemade Newtonians, and in addition we already had two suitable drive gear sets.

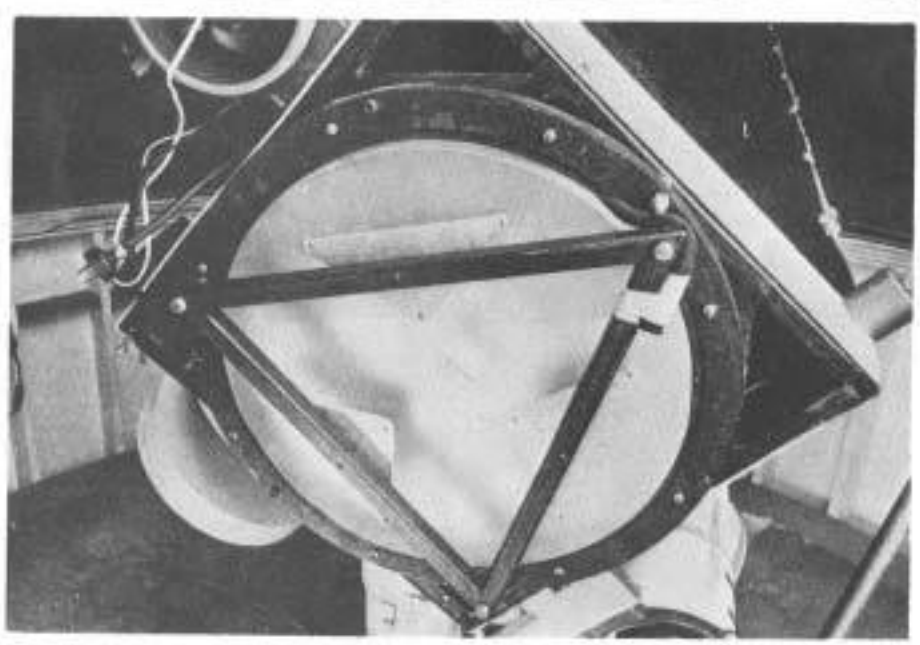
For the first mirror, I quite deliberately chose the least expensive source (Coulter Optical Co., Box K, Idyllwild, CA 92349). The 20" f/5.5 mirror they made for us was their first "large" one, and has given such satisfactory results that my subsequent choice of Coulter for the 14¼" mirror was automatic. I am told they will no longer make mirrors as large as 20", and I regard this as a real loss for home-builders of telescopes. However, the 14¼" is also very good, and I would not hesitate to buy another one.

The 20" blank was made from a 2⅛" thick

"Small" Telescope

The 20" f/5.5 telescope is carried on a massive mounting. Note the declination slow motion arm along the side of the tube.
Front and rear views of the tube show details of the indexable secondary mirror and primary mirror flotation system.





Pyrex plate and at first I worried about supporting such a thin mirror. However, I was reassured by E.T. Pearson (see A.J. Malvick and E.T. Pearson, "Theoretical Elastic Deformations of a 4 Meter Optical Mirror Using Dynamic Relaxation," **Applied Optics**, vol. 6, No. 7, July 1968), who worked out the support system for the 4 meter reflector at Kitt Peak, that this would present no design problem. In his words, "I can show you how to support a thin mirror, but not how to cool a thick one." His solution was a conventional multi-point back support (we used 9) with a "mercury bag" edge support. In this system the edge of the mirror is encircled symmetrically by a bag of mercury (in our case a rubber tube whose inner dimension in the direction perpendicular to the mirror is related to the mirror thickness by the inverse ratio of the densities of mercury and the mirror material. Thus, the mirror is in effect floating on the mercury. The resulting distortion of the mirror in the worst case (optical axis horizontal) is mainly a progressive thickening of the mirror toward the bottom, which only has the effect of tilting the optical axis by a very small amount. As for sag when the mirror is horizontal, to the first order the deflection due to any circularly symmetrical support system is merely a slight change in focal length, which is automatically corrected for in use. Details of both mirror mounts are shown in some of the accompanying photos. The mercury bag support is backed up by traditional edge supports, but these are set fairly loose and seldom, if ever, bear on the mirror itself.

Some features of the 20" are:

1) A square tube with an indexing secondary so that the prime focus can be sent out any side of the tube. One side has a 4 x 5 camera permanently in place and one of the three others is blocked off by the guide telescope.

Design of a Large "Small" Telescope

2) Both the mirror-mirror shaft and mirror shaft-spider fastenings must be adjustable for an indexing secondary to work.

3) Adjustments to square the tube to the declination housing, the declination housing to the polar shaft, and the polar bearing housing to the equatorial mounting plate.

4) A tangent arm declination slow-motion. This arm, to be stiff enough, was so heavy as to require a counterweight of its own. The drive itself is a very Rube Goldbergish arrangement whereby the tangent screw is belted to the DC declination drive motor with a thread, and the tangent screw is held engaged to the tangent arm by springs. Inside, where it doesn't show, are some bearing balls to eliminate friction between the tangent arm and the tube, which are also spring-loaded together. This system, although very unsightly, has proven to be completely free of backlash, and capable of being incremented fairly accurately to follow comets of known motion which are too dim or diffuse for guiding.

5) The polar axle is of 5" solid steel cut down at the bottom to fit a 3" lower bearing we already had (possibly a mistake), and the declination axle is 4", mounted in ball bearings in a box made from 7" square tubing with a ¼" wall. Both axles have adjustable friction clutches.

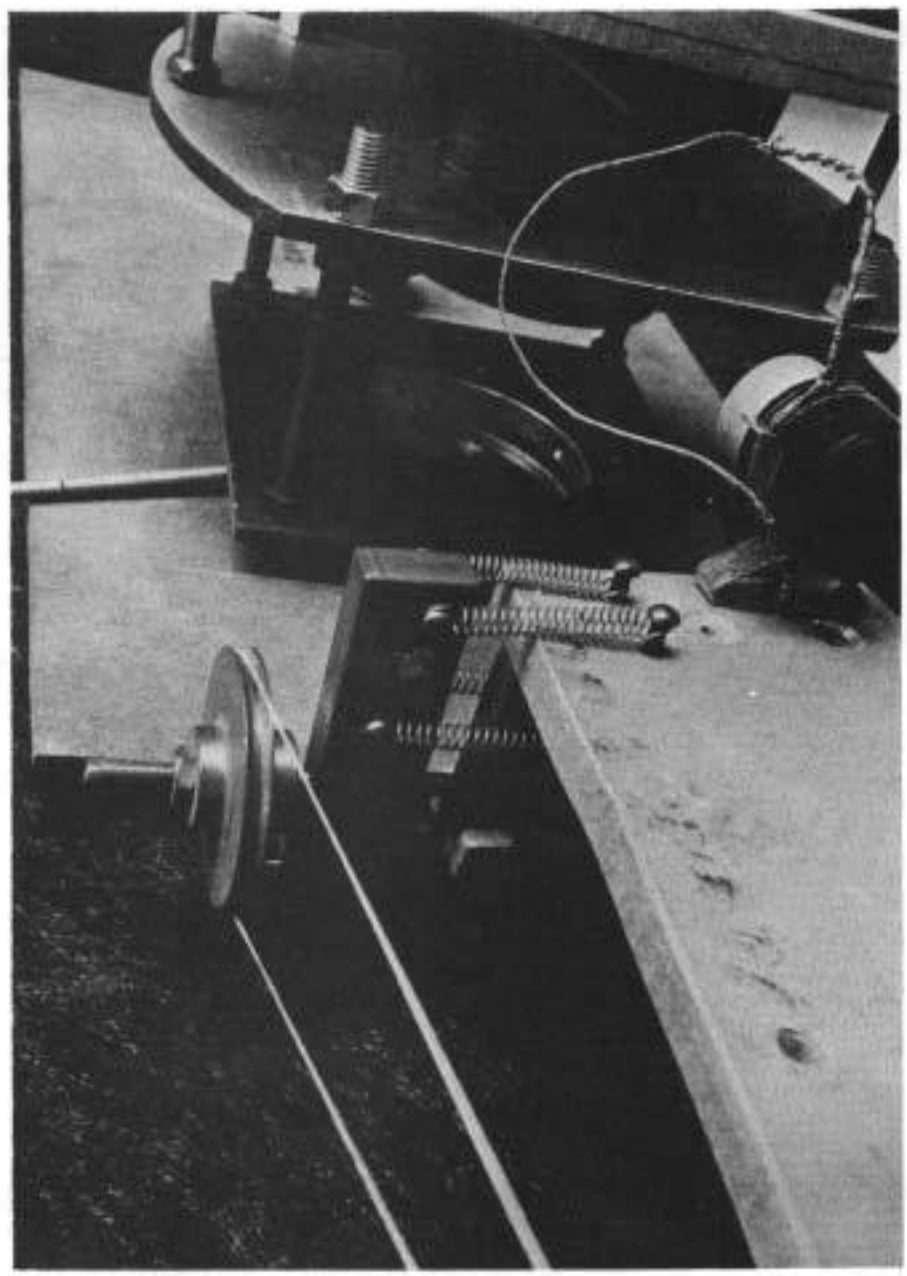
6) In retrospect, the equatorial head and pier of this instrument, fabricated from steel plate and a 12" pipe cap and pipe, are a disaster from the standpoint of adjustment in azimuth, but we were lucky in getting a good alignment the first time.

7) Circles are of heavily painted tempered Masonite, with markings indicated by drilled holes. The polar circle is mounted on the drive gear so as to be a true right ascension circle.

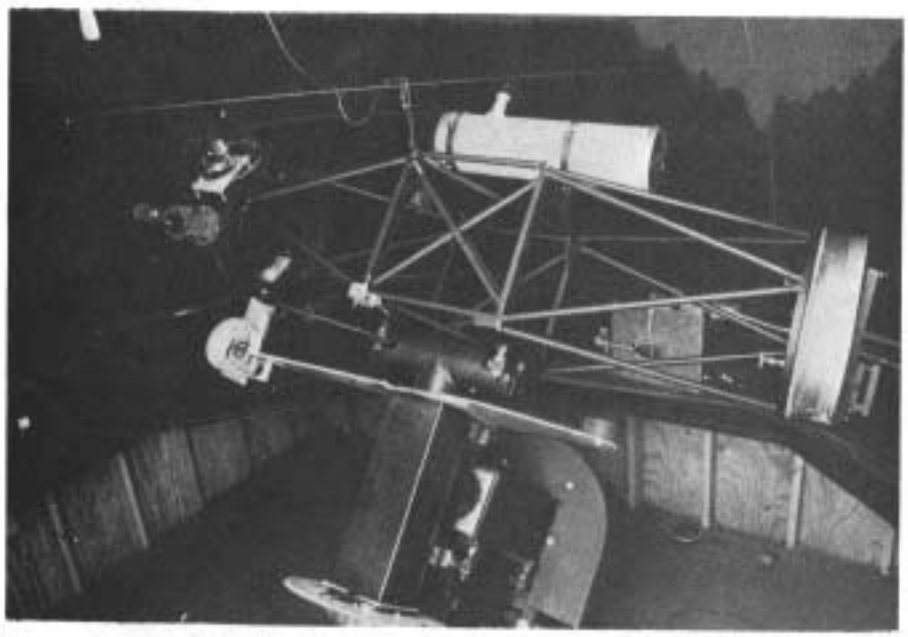
8) The worm housing support is temperature-compensated by being partly steel and partly aluminum, the combination calculated to match the expansion of the bronze drive gear.

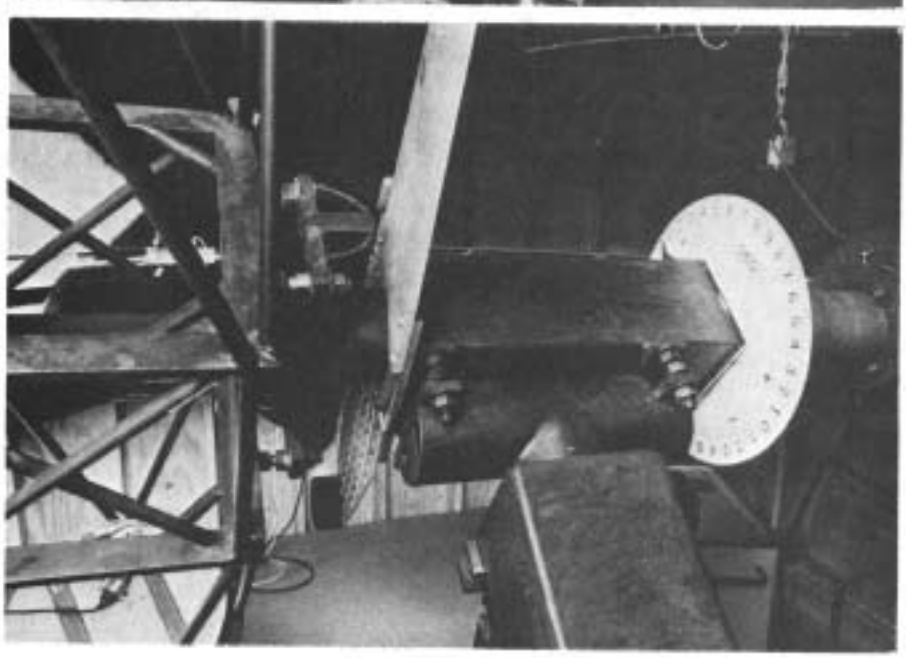
This telescope has worked well, in spite of the fact that it is quite large for a Newtonian and barely fits in the dome we had available. Its principal disadvantage is its square tube, which takes up too much room and is very ugly.

It is also awkward to use at the zenith due to



Alfred University Observatory





the relative inaccessibility of the eyepiece, even though one can observe visually from either of two different sides of the tube. Thus, when high course enrollment and some available funds led us to consider adding another instrument (the 14¼″ f/6), I decided on a Serrurier truss type of tube partly, I confess, to have at least one telescope that looks like a "big one." This type of truss construction, first used on the 5 m Hale telescope at Palomar, consists of a central box to which are attached eight pairs of small tubes defining eight triangles, four of which support each end of the instrument. In large telescopes, this arrangement is designed so that the ends of the tube sag equally and remain parallel. In this small instrument such careful design was unnecessary, and no attempt was made to match the very small, worst-case deflections. The overall result was a fairly light, immensely rigid tube in which the Serrurier trusses provided convenient transitions between the desired square cross-section of the central box and the round tube ends.

This instrument was also built in a very simple way, and a particular attempt was made to use standard steel shapes. The amount of machining was kept to a minimum, and wherever possible, parts were welded rather than bolted together. Some particulars:

1) The central tube box was fabricated from ¾″ x 2″ hot-rolled steel and the mirror cell, tube ends and top-end cage from flame-cut rings of ¾″ plate. Of these six rings, only three had to be machined: the mirror cell and the two mating bearing rings by which the cage rotates. (The upper ring of the cage was also machined, but only to decrease its weight.)

2) The center slugs from these six rings were bored to the diameter of the declination shaft and used as counterweights without further machining.

3) All bracing for the tube and upper end cage was of ½″ standard pipe, which was larger than necessary but chosen for aesthetic reasons.

4) The tee-shaped polar and declination shafts are of 5″ heavy wall pipe, which is much lighter and cheaper than solid rod. In addition, since the rigidity of a rod depends upon the fourth power of its diameter, only half of its stiffness is sacrificed by using pipe. While it is true that hot-rolled pipe doesn't machine quite as well as solid rod (being somewhat more inclined to chatter), and false ends must be welded in to accept centering holes, I experienced no real difficulty, and would do it the same way next time.

5) The polar and declination bearing boxes are of 7″ x ¼″ wall square tubing. Three-eighths inch plates were welded onto the box ends and then faced and bored to accept special thin ball bearings. (These bearings, four in all, cost half again as much as the optics for the telescope, and I would try to figure out a cheaper way next time.)

6) Like the 20″, the 14¼″ has threaded adjusters for polar altitude and for achieving perpendicularity of the optical, declination, and polar axes. In addition, the instrument base and pier top are large thick plates, whose relative orientation is easily and finely adjustable with tangent screws for alignment in azimuth.

7) The rotating top-end cage of the

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Design of a Large "Small" Telescope

telescope can be set at any convenient angle and has a 4" x 5" camera and eyepiece mount permanently in place. The secondary is rotated from one to the other by means of an aluminum bar which indexes into an adjustable clamp in each position. The entire cage is then squared onto the tube (as is the mirror cell) by three threaded rods.

This instrument has been quite successful, and proves easy to align. The open tube makes it susceptible to stray light in the camera, but since the telescope is 20 feet above the ground, only the Moon causes much problem. I will eventually construct a similar tube for the 20", but since it is a "downstairs" instrument, the tube will have to be covered, perhaps with fabric.

On each of these instruments the declination shaft has been machined straight (no taper), so that one can put a sensitive level on it for alignment purposes. The alignment procedure is as follows:

1) Collimate the mirror system.

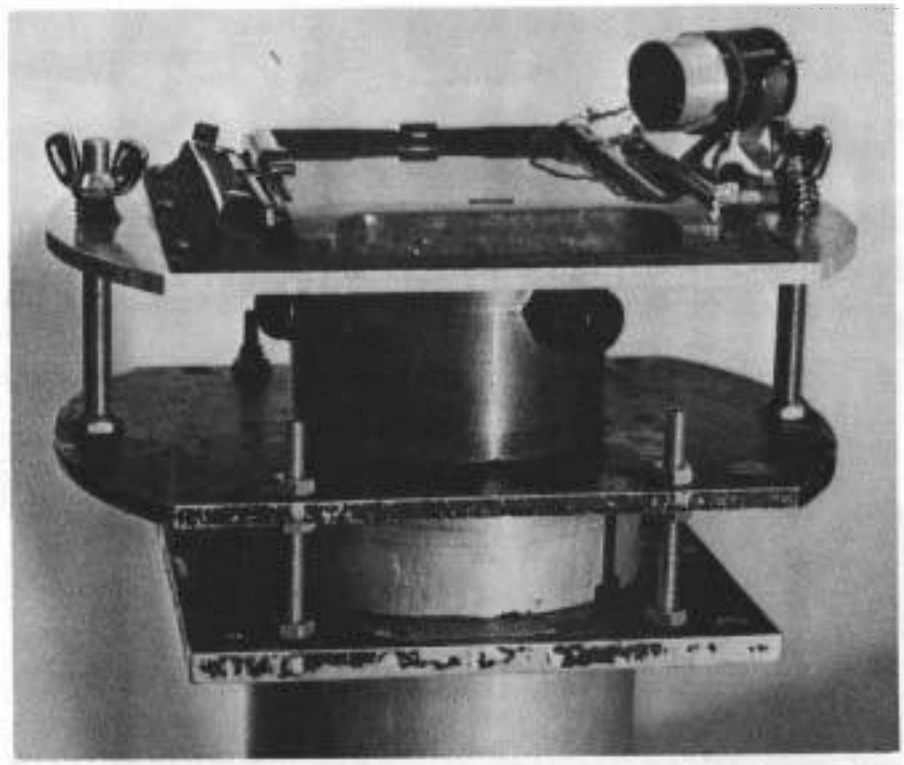
2) Set the altitude and azimuth approximately right.

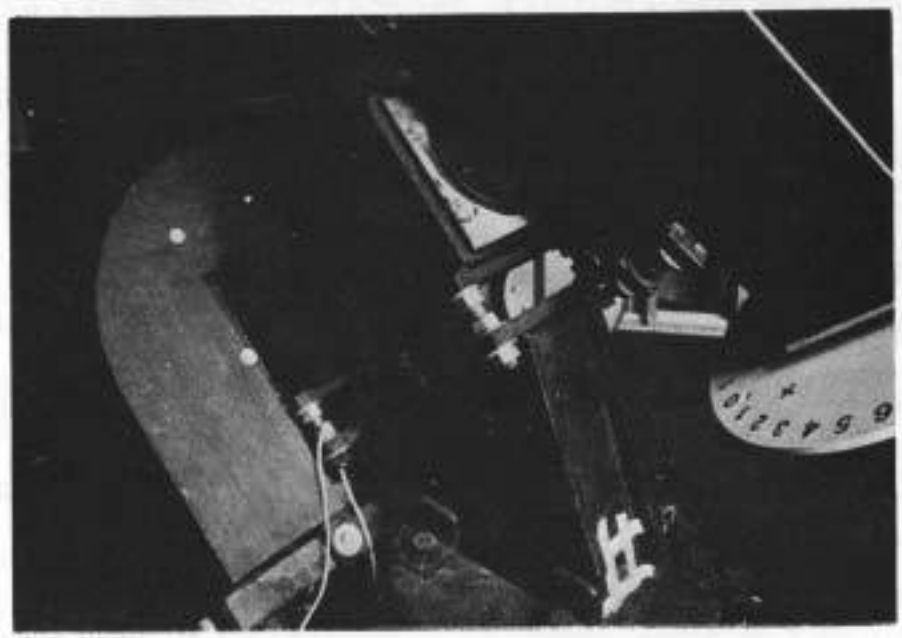
3) Using a reticle eyepiece, sight on a star that will soon pass directly overhead. (This eliminates error due to improper azimuth adjustment.) Record the instant the declination axis is horizontal, as determined with the level. Compare with the expected time of transit as determined from the star's current right ascension and the local sidereal time. Adjust out this error with the tube-declination axis adjusters. (If the axis is horizontal too early, the tube is pointing too far east relative to the declination axis.) If no sidereal clock is available, make the measurement and set an ordinary clock to the sidereal time calculated from the observed transit. Then perform the same operation on another star with the telescope on the other side of the pier. The error that shows up will be twice the actual error. (I have ignored the slight bend of the declination shaft due to the weights of the tube and counterweight, but in a stiff instrument, this will lead to only a very small error, part of which will be automatically adjusted out anyway).

4) Observe a star of approximately zero declination as it crosses the meridian. (This eliminates error due to the non-perpendicularity of the declination and polar axes.) If the star moves north relative to the reticle, it means that the azimuth of the mount is to the east of south and to the west of north. (Star is still rising when telescope is already at its meridian or telescope is past its meridian when star actually transits.) Adjust the azimuth to remove this problem.

5) Observe Polaris at either upper or lower culmination, declination shaft horizontal (the altitude error of the mount is eliminated in this configuration), and get it on the crosshair with the declination shaft-polar shaft adjustment.

6) The only remaining adjustment is the altitude of the polar shaft, and this can be checked by observing Polaris directly east or west of the pole, declination shaft "vertical" (telescope pointed at + or - 6^h). Alternatively, a clinometer can be used on the polar shaft to set its altitude. Notice that these adjustments must be made in the order described so that at each stage the adjustments not yet made will not enter in.





Another common feature of these instruments (and of our 9" refractor and 16" reflector as well) is their 4" x 5" cameras. These cameras, identical except for the plate by which they mount to the telescope, are based upon a focusing tube which butts into a greased recess in the back plate and threads into a front plate at the other end. The camera has two large threaded rods fixed to the front plate and sliding through the back plate, which they hold in place by means of thumbscrews and springs. The back is a standard Graflok, and the whole thing squares onto the telescope with four threaded rods. The small magnifier shown is for focusing the camera, although the more experienced use a knife-edge, which is much more accurate and actually easier once you get the hang of it. Each camera also has a focusing screen converted into an eyepiece holder so that on "deep-sky nights" the camera need not be interchanged for visual observations.

John Stull
Alfred University
Physcis Department
Alfred, NY 14802

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Jet to the Moon

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It might interest you to know the history of this photograph. This past summer the National Science Foundation sponsored a four-week institute at Alfred University entitled, "Observational Astronomy for School Teachers." One of the students, John K. Wakeman, a junior high teacher in the Orchard Park, N Y school system, spent part of his observing time photographing the Moon at a number of different phases, using the 14¼" f/6 Olson telescope. Thus, on Monday night, July 17, he took several exposures of the Moon on Kodak SO-115 Technical Pan Film. Like all good observers, he was careful to record the time, a fact that was later to prove crucial.

Since there was still some film left in the camera, he left it in and also photographed the Moon for the next two nights. On Thursday night, the last night of the institute, the sky was quite hazy, and so John quit early to develop the film. As he was hanging it up, I heard him say of the Monday night pictures — "Here's the best one (the 1/250 sec. exposure), but it's got an ugly scratch on it." I had loaded the film for him (John doesn't like our kind of film tank at all!), and I was puzzled, since I had had no difficulty with it. To see what had gone wrong, I took out the pocket magnifier I always carry and examined the negative close up. I need not say what excitement then erupted, since none of us, even John, had had any inkling of what had happened. (When photographing the Moon, one first points, then focuses, the telescope and then backs away from it and waits for a few seconds to let any vibration die away before making the exposure, so during the second it took the airplane to cross the moon, nobody was watching!)

The next morning Roger Carr, the principal instructor at the institute, identified the airplane as a DC 10, and Marty Moore and Al Littell in the University Relations Office submitted the photograph to United Press International. Ultimately, UPI declined to release it, fearing that it might be a hoax, and it was submitted to Associated Press. We then decided to attempt an identification of the individual airplane. Since (thanks to John) I knew that the photo had been taken at 9:35 p.m. EDT (0135 GMT), I could look up the celestial coordinates of the Moon and from these, the time and the longitude and latitude of the observatory, calculate the altitude and azimuth angles of the airplane. To make further calculations, however, I needed to know its size, and I phoned Douglas Aircraft, the manufacturer, to find out. I was put in touch with Elayne Bendel, Senior Representative in the External Relations Division, who gave me the dimensions of the regular and long range versions of the DC 10. Now I was able to compare the relative sizes of the Moon and airplane images, and to deduce that the plane was 13 miles south-southeast of the observatory and flying at about 34,300 feet. Since both wingtips are showing, I could tell that the plane was pointed about 5° toward the telescope, and with the known azimuth angle, that meant that it was on a heading of 062° (28° north of east), possibly in a slight climb. Additionally, the assumption that the plane was not banking allowed me to guess that it was the long range version since with a shorter wingspan, a short range DC 10 (4000 miles is short range?!) would have had to be banking about 2° away from the telescope.

I communicated these numbers to Elayne at Douglas, who began what was to become a long and arduous search of the schedules of the 36 airlines who use DC 10s to see who might have had one near Alfred at the right time. This search produced no close matches but by this time she was hooked and called the New York Air Traffic Control Center, which has charge of commercial aircraft in our area. They told her that had she called within a few days of the event they could easily have asked their computer, but that the volume of traffic necessitates discarding all but the immediate past "progress tapes" of individual aircraft flights. They did say, however, that the heading ruled out New York as a destination, that it could be a Boston or overseas flight, but that the altitude sounded high for the former, especially if the airplane were still climbing.

Scheduled airlines having been ruled out, Elayne turned as a last resort to the long list of charter airplanes who fly DC 10s, and began phoning them one by one, a potentially endless task. But here she got lucky, because after only three calls Pat Miller, Coordinator of Advertising and Sales Promotion for Trans International Airlines, identified the flight as one chartered by Arthur's Travel Center of Philadelphia, which left Cincinnati at 8:45 p.m. EDT (0045 GMT) and landed in Shannon, Ireland at 0745 GMT. A subsequent call to Arthur's revealed that the plane was carrying several college alumni groups from Ohio and Kentucky.

Meanwhile, A.P. had expressed skepticism about the photograph and wanted to see the negative, which we were reluctant to send through the mail. (It gives one confidence in both AP and UPI dispatches to see the care they take in documenting their sources.) They agreed instead to examine contact prints of the negative which would also show the negatives adjacent to it, and so we sent them these plus a number of other prints at various enlargements up to 28 times negative size and news of Elayne's detective work. Apparently satisfied, they released the picture, which has apparently been printed in several hundred newspapers here and abroad.

Of course we can't take any credit for having taken this photograph. After all, we simply had a telescope pointed in the right direction at the right time; Lady Luck did the rest.

John Stull

■

A 10-Inch Portable Open Tube Newtonian

In thinking about the design for a new telescope, a number of things restrict what the final instrument will look like. Uppermost in my case was the need for portability. After several of my neighbors erected decorative mercury vapor lamps in their yards, I was forced to do my viewing at a remote location — but the telescope still had to be stored at home! Additionally, I enjoy chasing grazing occultations. I decided any instrument that I built would have to fit in the trunk of my car.

My 6- and 8-inch telescopes (both of 48-inch focal length) met this requirement, but I wanted a larger instrument. It was my intent to grind a 12-inch mirror of about 60-inch focal length, but this size wouldn't fit inside my automobile without being broken down into sections.

Another challenge of telescope making — one which gives me pleasure — is trying to make the instrument (excluding the mirror) from things which are at hand, or are readily available. Finding a novel use for ordinary things provides me with stimulus.

It was, therefore, my good fortune to meet Larry Higgins of Miami Springs, Florida, at the 1976 SERAL convention in St. Petersburg. Larry is a genius at using available materials. He showed slides of a closed cylindrical wooden tube he had built for his 8-inch f/8 telescope. The workmanship of his mahogany veneer finish would have made a master cabinetmaker envious. In addition, the eyepiece end of the tube rotated independent of the rest of the assembly.

I saw some ideas that would be suited to my purpose, so later that summer I visited Larry in Miami Springs. The trip turned out to be worth more than the thrill of looking at and through an excellent telescope. Larry gave me a number of good ideas, and further insisted that I take his special lathe for forming wooden tubes and also a partially polished 10-inch f/5 mirror and tool.

In completing this mirror's polishing, the surface became scratched. I reground with fine abrasives, then repolished and figured it. The mirror has a focal length of 57" — close to what I orginally wanted.

In the meantime, I had acquired a two foot length of 10¾" I.D. P.V.C. tubing. I sawed it into two 11" long pieces and carefully squared the ends with a hacksaw and file. One piece would protect the mirror from dew and stray light, the other protect the diagonal and keep stray light from the eyepiece.

Next, I cut six identical rings from ¾" exterior plywood, using a router and trammel point. One pair of rings was faced with formica to make bearing surfaces for the rotating tube's top segment.

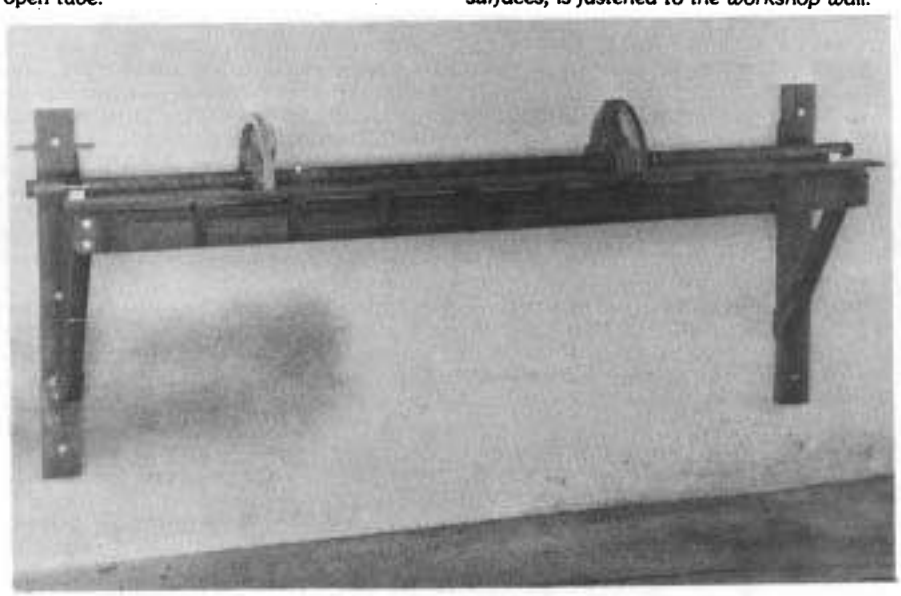
Two rings were fastened around the outside ends of the two P.V.C. tubes while two others (including one of the formica-faced pair) were attached ¾" in from the opposite ends of the tubes. The remaining rings were used as spacers to get the ¾" spacing correct. (The rings reinforce the tubing and keep it cylindrical. In addition, they provide the means for attaching the tube segments to the center open part of the tube between the end pieces.)

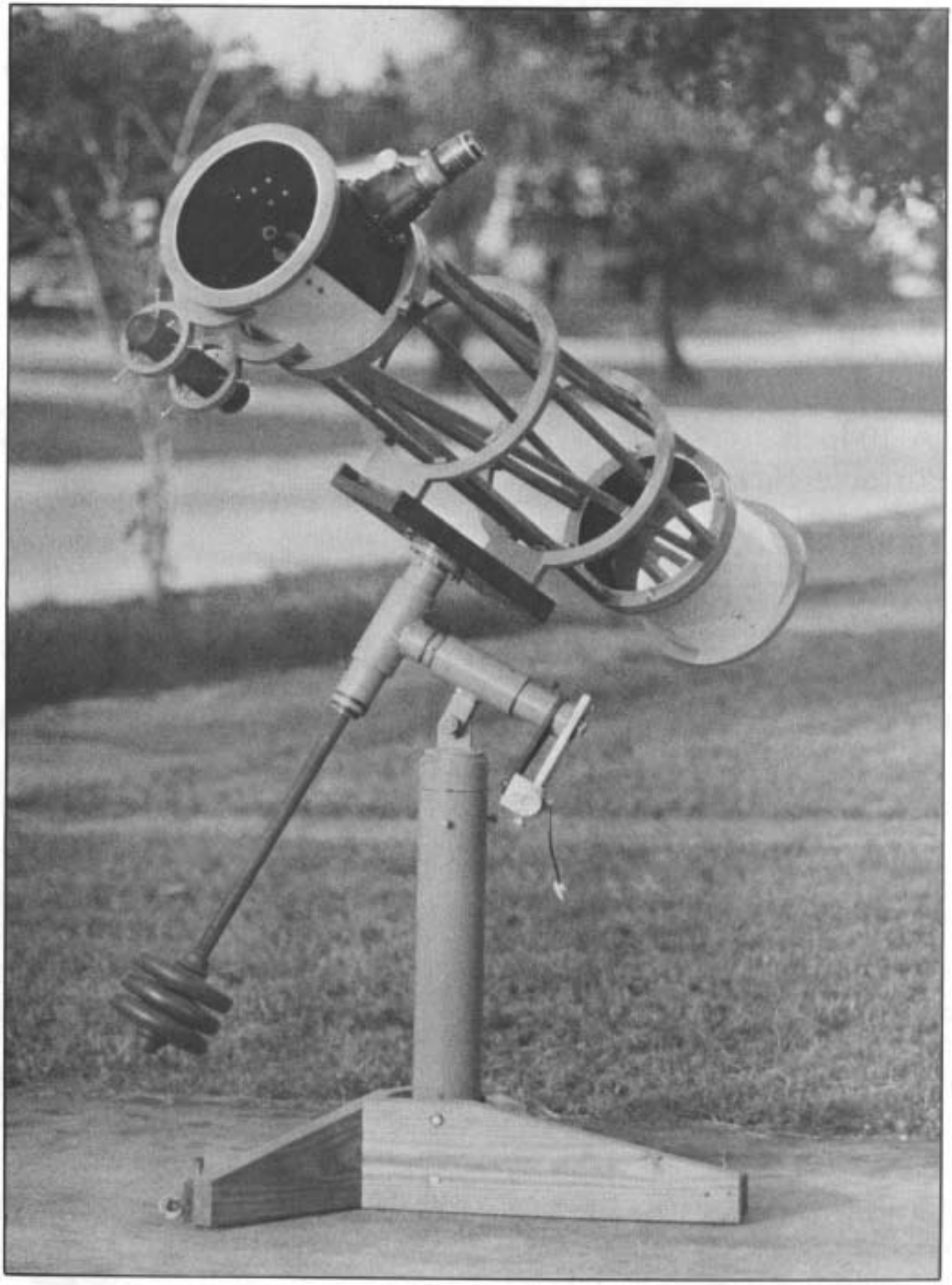
Larry's lathe is a very simple affair, a horizontal open framework with bracing at each end for support. The bearings are aluminum blocks with a concave surface that has a radius equal to that of the long piece of straight pipe which acts as the axis of the unit. No restraints are needed to hold the axle in the bearings or in position, as little force is used in assembling the center portion of the open tube.

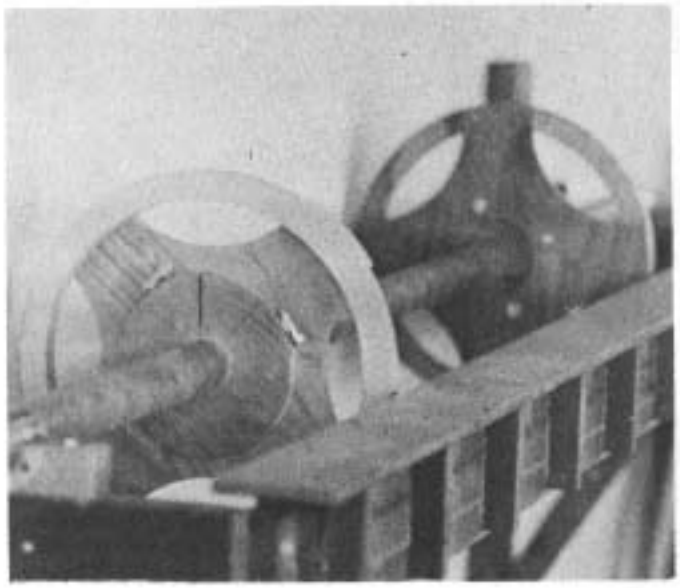
Larry's lathe made it very easy to fasten the rings in place so that their centers were in line, with their exterior planes parallel to each other and perpendicular to the optical axis. The pictures show pretty well how each step was done.

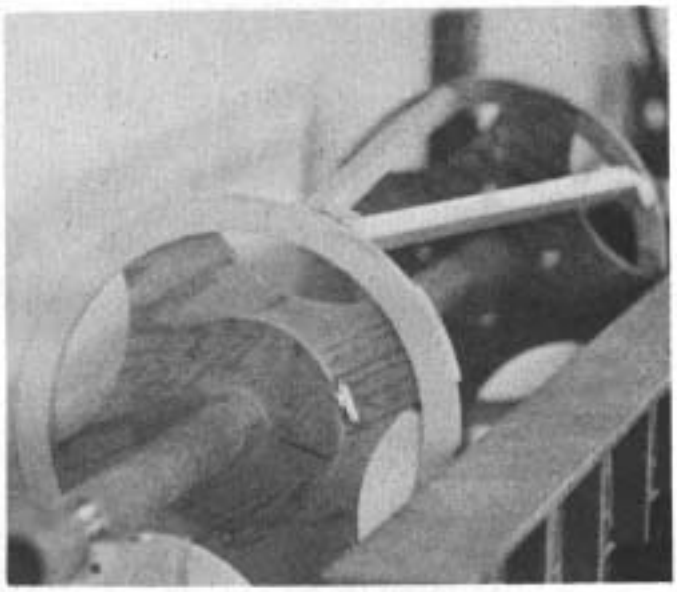
The tube was assembled on the lathe. To hold the end rings centered on the pipe, I cut wooden support plates that slipped over the pipe. Four segments were cut away where the struts were to join the rings. The holes in the support pieces were intentionally sloppy so that they could be shifted for centering. I attached the support plate to a split hub clamped to the pipe axle with large hose clamps. By mounting both end rings in this manner, I could adjust them so their centers were in line and their exterior planes were parallel and perpendicular to the optical axis. The long strip of thin wood along the side served as a reference, and the rings were centered by noting when the ring edge stayed a uniform distance from this strip as the lathe was rotated on its axis.

Below: The alignment lathe, consisting of a simple wooden frame and two bearing surfaces, is fastened to the workshop wall.









This page: centering, clamping, and gluing operations are done on the lathe. Opposite page: the rotating upper tube section is held by wooden clamps; the mirror section is just bolted on.

A 10-Inch Portable Newtonian

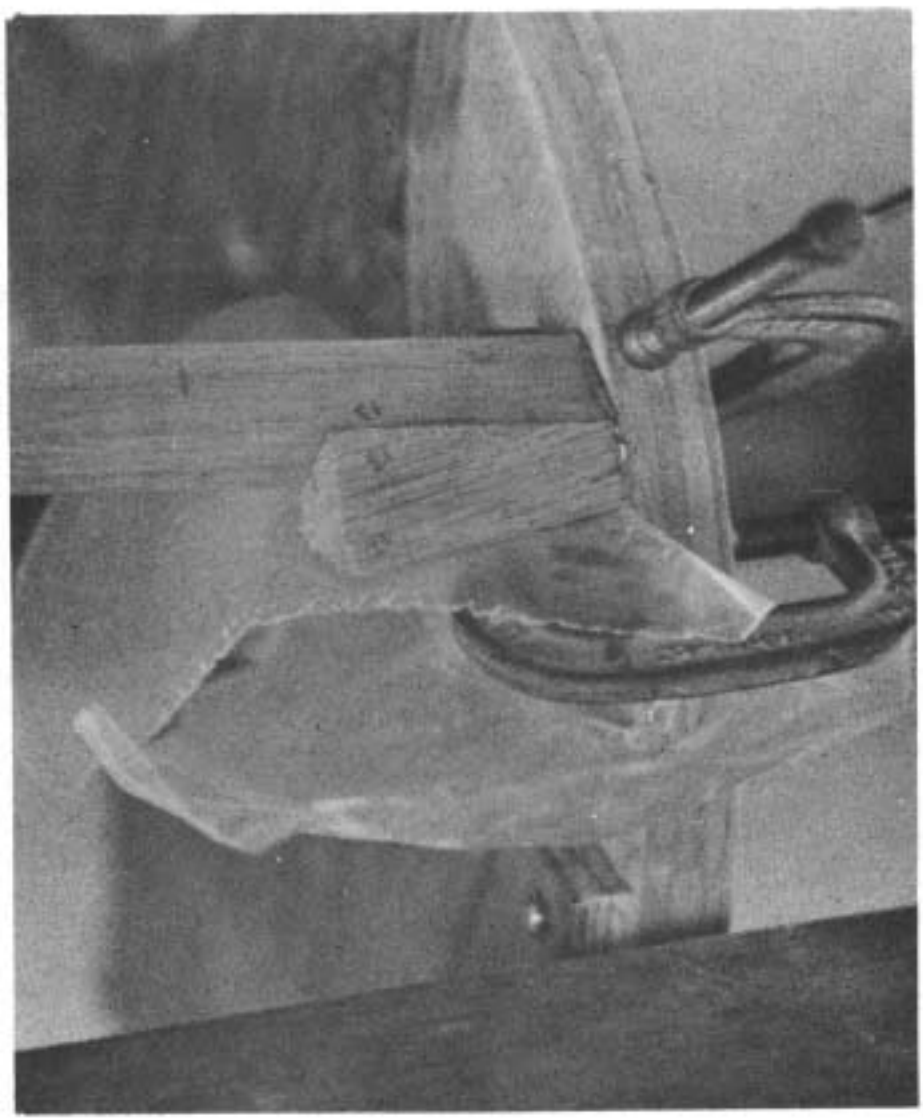
At this point, a simple freehand sketch showed that the struts would need odd-angle cuts. I made a careful, half-scale drawing, and this clearly demonstrated that filler pieces would also be required where pairs of struts joined the rings. Once I'd determined the dimensions, I cut the pieces out of oak having a ¾" square cross-section. All eight struts were clamped and cut together so that each would be identical to the other in length and angle.

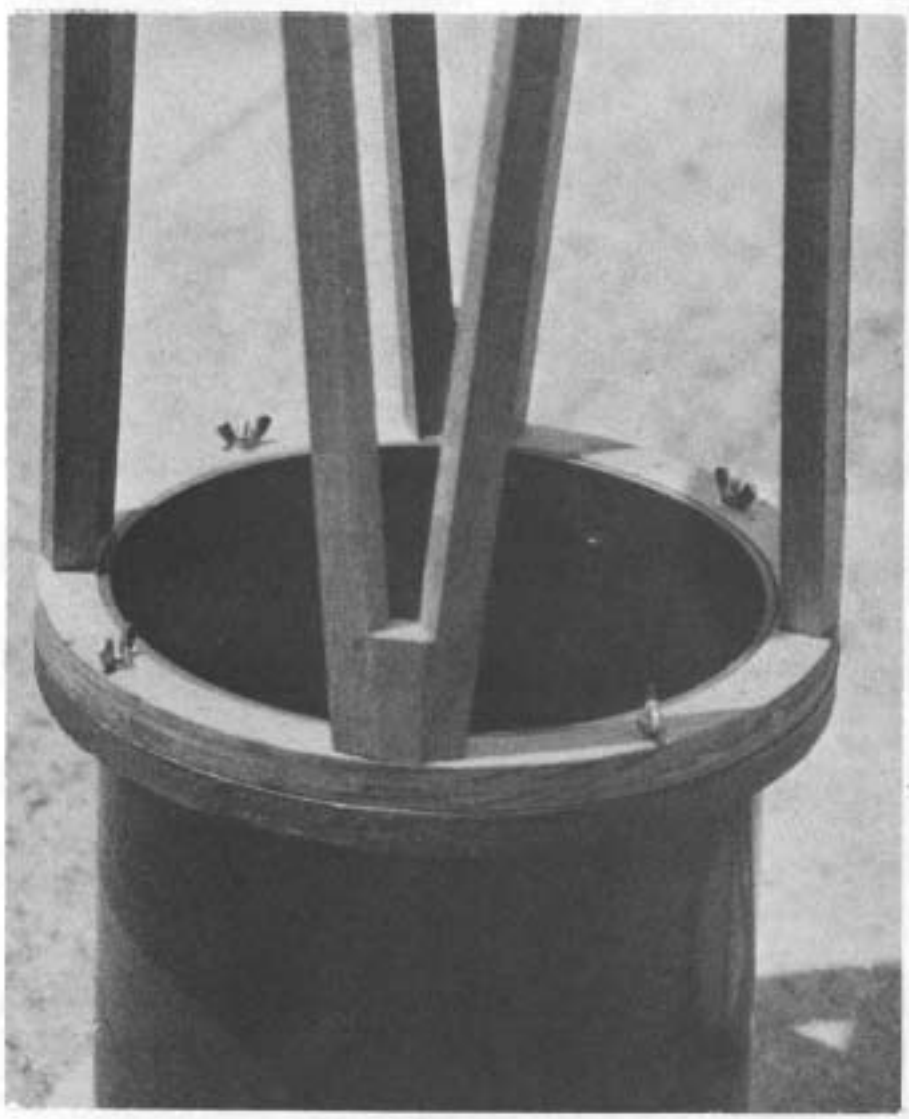
The completed struts had an angle of 57½° at each end. Each filler piece was glued to one end of each strut with epoxy resin to minimize the number of pieces that had to be clamped at any one time. The struts were then glued, one at a time, between the rings. When all the struts were assembled, the framework was removed from the lathe. The glued joints were strong, but the outer lamination of the plywood had separated adjacent to two of the glued joints. I reglued these back together and got around the problem by drilling holes and fastening the struts with dowels. The frame has now been in use for more than six months with no further separation problems. The framework assembly is adequately rigid, with no sag or flexure.

The primary mirror cell end is attached with four carriage bolts, washers, and wing nuts. The eyepiece end is rotatable on the formica surfaces and is held in position by three oak clips and bolts with wing nuts. The clamps open completely for removing the upper end piece.

The primary mirror is vulnerable to things being dropped on it, but it's also readily available for cleaning. Storage of three small units is easier than for one large one. Also I can cover the primary mirror with shower caps and store it face down. The diagonal is also stored face down and is wrapped in a plastic bag.

The mount was designed by me and mostly fabricated by me, except for the welding and machine work on the head. This work was





done by Ron Lippard of Jupiter, Florida. The pier consists of a 4" iron pipe of the type used by utilities under roads. I squared it off by wrapping a strip of paper with a clean, smooth edge snugly around the pipe so the surfaces overlapped. This defined a circle perpendicular to the axis of the pipe. I then transferred the line to the pipe surface and carefully cut along it with a hacksaw. If done carefully, just a little smoothing with a file will produce a clean, square surface.

The bearings are simply 6" long, metal-to-metal thick-wall tubing machined to a close fit. Plenty of white lubricant is used to keep it turning easily. The mount tracks smoothly providing it's balanced properly.

The clock drive is a Wolf gearless drive (which really has a gear), is really inexpensive, and does what I want it to do.

The feet are made from 2" × 6" pine cut to the appropriate shape. The idea was taken from Sam Brown's **All About Telescopes.** The two front feet have rubber casters which touch the ground when the mount is tipped forward so it can be rolled to a new location.

Leveling screws function through tapped oak blocks attached to the feet. I place three 2" square plywood blocks under the leveling screws when operating on soft ground.

I can slide the entire tube assembly a full 6" parallel to the optical axis, so the instrument can be balanced with a camera, large Erfle ocular, ordinary eyepiece, or other accessories. Finally, the eyepiece assembly was painted flat black halfway around the cylinder so stray light will not be reflected from a shiny surface into the eye.

The mount is also strong enough to support the optics for a 12½-inch f/4 which I obtained from the estate of the late Al Warner, formerly of the Smithsonian Astrophysical Observatory's Project Moonwatch. This large instrument, although technically portable, is very cumbersome. Including its counterweights, it weighs over 100 pounds. My new 10-inch — with counterweights but excluding the mount — weighs less than 60 pounds, and is much more convenient to use.

The finder is a binocular lens mounted in a 2-inch P.V.C. pipe and fittings, and the eyepiece is two simple lenses also in P.V.C. tubing. P.V.C. is very inexpensive and handy to work with.

Although the weather in Florida last summer didn't favor astronomy, the few good evenings we had revealed things like individual stars resolved all the way across the face of M-13. I am most pleased with the results of this instrument. I put it up against a 12½-inch of similar focal length at a star party, and everyone agreed that the only noticeable difference was in the brightness of the respective images.

Incidentally, I present this instrument as a candidate for the Most Traveled Telescope Award. I packed the entire thing into the trunk of my car and took it to Houston during a six month temporary assignment there. It now makes a weekly trip between my work in Palatka, Florida to my home in Lake Park — about 250 miles each way. It has made eight trips so far, and with the trip to Texas, has covered about 6,200 miles. It goes where I go!

Richard W. Lasher
814 Date Palm Drive
Lake Park, FL 33403

■

A Compact All-Spherical Catadioptric Newtonian Telescope

Spherical optical surfaces are easier to make than parabolic ones — every TM knows that. And everyone wants a telescope that's compact. The telescope described in this article contains only spherical surfaces (including the primary mirror), and fits a well-corrected f/6 optical system into a tube the size of an f/4 Newtonian.

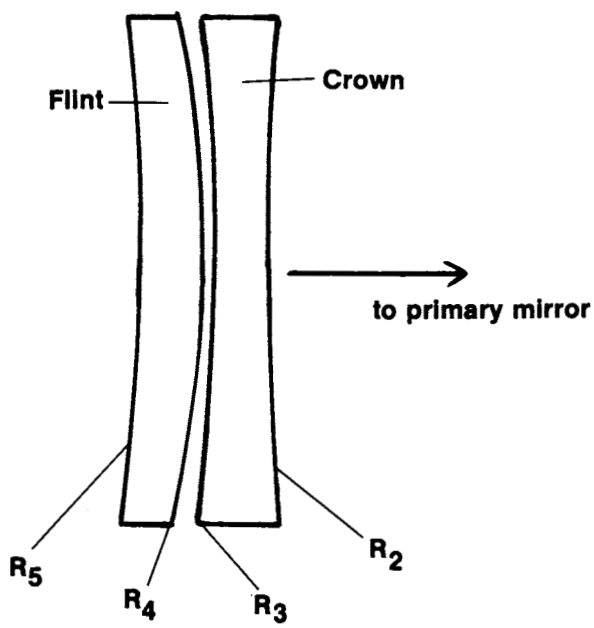
The authors have had the repeated pleasure of viewing through one of the original telescopes of this type made by Robert T. Jones (see **Sky and Telescope**, September 1957, page 548). This design, with its blend of simplicity and excellence, will get even more attention when TMs learn that it has a better field than an equivalent f/6 Newtonian. There is also the intriguing potential that with the addition of two more lenses, this design can become a superior f/5 photographic instrument.

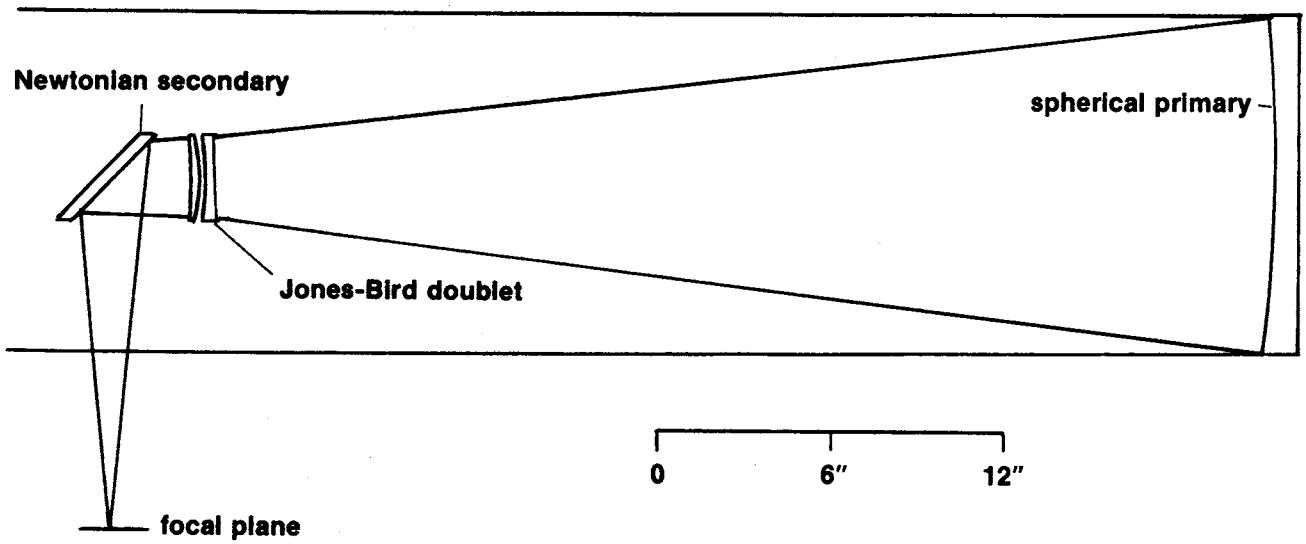
We redesigned the Jones system using a computer. Our final design for a 12-inch system (using a negative doublet, with a minor glass change for improved transmission), results in an instrument superior to the original. We began reducing the diameter of the Jones negative doublet to 2.6 inches (an obstruction ratio of 22% for a 12-inch), to improve axial definition. But the smaller corrector led to fairly large astigmatism residuals, so we reduced them by putting less power, or amplification, into the correcting lenses. We felt that the f/6 final focal ratio of our new design had an adequate focal length for most observing work.

The design has excellent correction. Correction of spherical aberration is excellent; it has fine coma control and good control of spherochromatism. The f/6 telescope has the compactness of an f/4 Newtonian without the difficulty of figuring a fast parabolic primary. Astigmatism is comparable to that of an ordinary refracting or reflecting telescope and is, in part, corrected by the positive astigmatism present in most eyepieces. What astigmatism remains is easily tolerated by the eye. Be warned however: this astigmatism is not acceptable for 35 mm photography. The eye is an automatic averaging focusing mechanism, but film is not.

For image quality, compare the f/6 visual system at 1/6 and 1/3 degrees off-axis to the same focal length parabola in the accompanying drawing. Neither a Cassegrainian or Dall-Kirkham design work at this low focal ratio, so we have not included them in the comparison. The glasses used, BK-7 and F-2, are standard glasses. They would give a longitudinal (along the optical axis) secondary spectrum of 1/1800 of the system focal length if used as an ordinary achromatic doublet. However, this catadioptric system has a longitudinal secondary spectrum of 1/23,000, about 13 times less: typical of arrangements where the elements causing the color are not introduced into the system until near the focus. The blur, or transverse spot diameter caused by secondary spectrum at 70% of the aperture where the F' and C' wavelengths (4800 Angstroms and 6439 Angstroms) are united and crossing the optical axis is about 0.0064 millimeters in 5461 Mercury light. Although this is somewhat larger than Conrady's limit for a 12-inch f/6 system (he would allow about 1¼ Rayleigh limits of secondary spectrum as a rule of thumb), our study indicated that this can be relaxed because of the weighting of the F' and C' ends of the spectrum. If the peak response of the eye is rated 100%, then these two colors are at 10% and 15% respectively. Refocusing also improves this somewhat. So we do not believe secondary spectrum is a problem. As it is, it's still about 12 times better than the typical refractor and almost 6 times better than a three element apochromat.

The best way, perhaps, to show this is to compare the axial modulation transfer function (MTF) of an f/6 parabola to the new design. We have weighted the three colors (5500 Angstroms 100%, 5100 Angstroms 50%, and 6100 Angstroms 50%) to approximate the photopic response of the eye. We feel that the comparison is excellent.

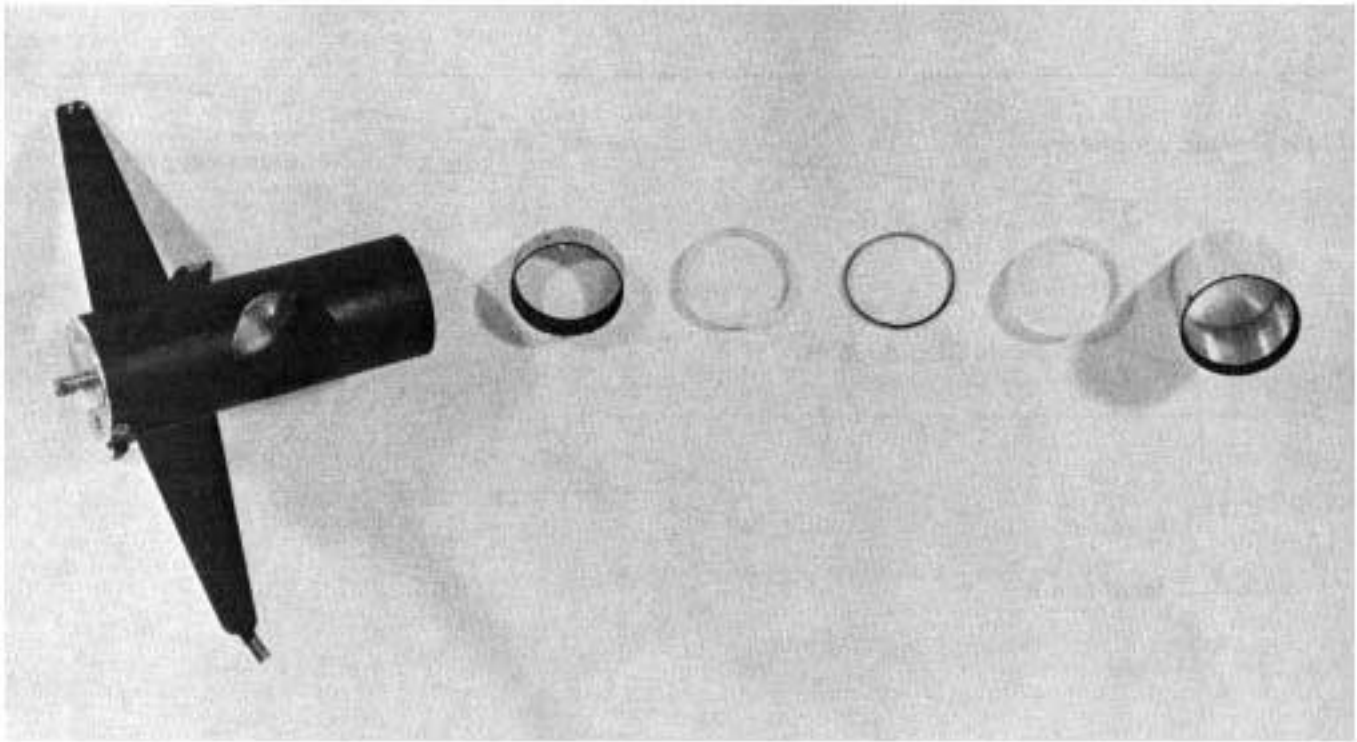




JONES-BIRD TELESCOPE

Specifications
(in inches)

Primary - Pyrex					
Dia.	**6.0**	**8.0**	**10.0**	**12.0**	**12.5**
R_1	**-46.889**	**-62.519**	**-78.148**	**-93.778**	**-97.685**
t_1	**1.0**	**1.375**	**1.75**	**2.125**	**2.125**
Air	**18.302**	**24.402**	**30.503**	**36.603**	**38.128**
Crown Lens - (517645)BK-7					
Dia.	**1.313**	**1.759**	**2.198**	**2.638**	**2.748**
R_2	**9.950**	**13.266**	**16.583**	**19.899**	**20.728**
t_2	**0.151**	**0.201**	**0.251**	**0.301**	**0.314**
R_3	**-5.244**	**-6.965**	**-8.707**	**-10.448**	**-10.883**
Air	**0.018**	**0.024**	**0.030**	**0.036**	**0.0375**
Flint Lens - (620364)F-2					
Dia.	**1.313**	**1.759**	**2.198**	**2.638**	**2.748**
R_4	**-3.121**	**-4.161**	**-5.202**	**-6.242**	**-6.502**
t_3	**0.169**	**0.225**	**0.282**	**0.338**	**0.352**
R_5	**-5.344**	**-7.125**	**-8.906**	**-10.687**	**-11.323**
BFL	**7.426**	**9.901**	**12.277**	**14.852**	**15.471**
EFL	**36.0**	**48.0**	**60.0**	**72.0**	**75.0**



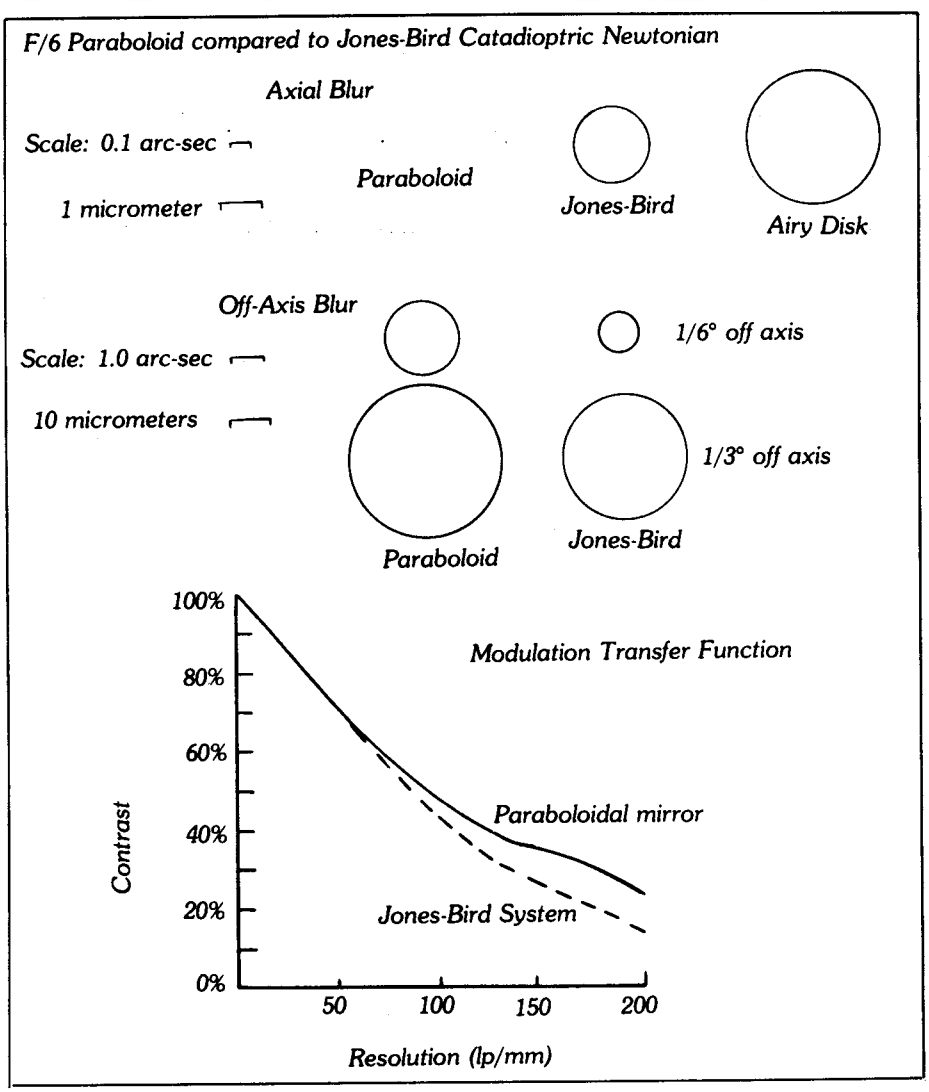
Compact All-Spherical Catadioptric Newtonian Telescope

Although this system is not as simple as a Newtonian (that is, mounting the corrector lenses is more of a problem than the mounting of a flat secondary), centering is not as difficult as it is for typical Cassegrainians because the amplification is not as great. Furthermore, when you tip a reflecting element, the error is more noticeable than when you tip a refracting element, as a ray is deviated by twice the angular error with a mirror but only by a fraction through a lens. Nor is there any requirement for a hole in the primary mirror or extensive baffling as in the Cassegrainian. And best of all, the difficult conic surfaces are replaced by spherical lenses and a spherical mirror.

Well, if all that hasn't convinced you, you're not going to be convinced unless you build one. The table of specifications lists the various parameters for standard mirror blanks and the minimum size for the lens blanks. Remember that you'll need a diagonal mirror the size of the lenses to fold the light path to the side of the tube for viewing.

The correction of this system was done using a program written by William Peck of Genesee Computer Center, Inc.

This material was taken in part from a paper by Tom Bird and Alfred Bowen at the 1976



JONES-BIRD TELESCOPE

(Glass fine annealed, Grade B)

JONES - BIRD TELESCOPE

Glass Type	Dia.	Ct.	Core Size	Unit Price
Primary Diameter 6 Set #1.				
BK-7	1.313"	.244"	1.325"	1.80 each
F-2	1.313"	.239"	1.325"	2.00 each
Primary Diameter 8 Set #2.				
BK-7	1.759"	.316"	1.775"	2.40 each
F-2	1.759"	.309"	1.775"	2.75 each
Primary Diameter 10 Set #3.				
BK-7	2.198"	.387"	2.245"	2.40 each
F-2	2.198"	.380"	2.245"	2.75 each
Primary Diameter 12 Set #4.				
BK-7	2.638"	.459"	2.750"	4.80 each
F-2	2.638"	.450"	2.750"	5.70 each
Primary Diameter 12½ Set #5.				
BK-7	2.748"	.478"	2.750"	4.90 each
F-2	2.748	.467"	2.750"	5.75 each

The diameter of the lens blank is the nearest oversize core cutter available at the supplier.

Costs are approximate and will vary with the changing dollar and yen values.

SOURCE: Recon Optical Glass, 2660 Columbia Street, Torrance, CA 90503
Attention: Elie Davis

JONES-BIRD TELESCOPE

(Coatings)

Primary Diameter	6 Set #1	8 Set #2	10 Set #3	12 Set #4	12.5 Set #5
Cost	All sets $20.00 each plus $2.00 for return UPS				

The cost is for the two lenses, crown and flint (BK-7 & F-2) to be coated on both sides with magnesium fluoride.

It is recommended that both lenses be sent at the same time to keep down the record and bookkeeping chores by the supplier.

SOURCE: Evaporated Metal Film Corp., 701 Spencer Road, Ithaca, NY 14850
Attention: Mike Shey

meeting of the Southwest Regional Convention of the Astronomical League in Dallas, Texas. The paper also appears in the proceedings of that meeting.

Thomas Bird
94 Gaselight Lane
Rochester, NY 14610

Alfred V. Bowen
9736 Forest Lane #1199
Dallas, TX 75243

ED NOTE: Although the paper of Bird and Bowen was presented in 1976, no prototype of the design had been fabricated and field-tested until the middle of 1978. It was to all intents and purposes, a "paper telescope" — conceived on a computer but yet to be given birth in glass! In November 1978, several members of the McDonnell Douglas Astronomy Club and I had the pleasure of working with a 6-inch version of the all-spherical catadioptric Newtonian that had been built by Jim A. Wilson of Hazelwood, Missouri. Although the lenses were yet to be coated, its performance was so outstanding that both Jim Wilson and another member present have ordered glass to make a 12-inch instrument.

A major problem in the hobby of telescope making today is the trend of many companies to have a minimum charge. Any purchase less than this amount is charged at the minimum regardless of how small it may be. This applies in particular to suppliers of optical glass and it's just about impossible for the hobbyist who needs a $10 piece of glass to pay the $50 company minimum charge. Fortunately, it has been possible for the staff of TELESCOPE MAKING to find reliable and reasonable sources of two vital services in catadioptric telescope fabrication. The accompanying table gives the diameter and thickness of optical glass for the Jones/Bird design, the cost of individual items and the total cost of each set of glass blanks for the parameters listed in the article. The supplier who has shown an interest in handling small glass orders from telescope makers is Recon Optical Glass, 2660 Columbia Street, Torrance, CA 90503, Attention: Elinor Davis. To expedite handling orders, specify by set number. If you wish thicker or thinner rough blanks, then WRITE the company for new cost estimates. Please WRITE — do not phone.

In having lenses antireflection coated to prevent ghosts and increase transmission, it is hard for telescope makers to escape a minimum charge problem. The second table is one for having the two lenses of the Jones/Bird telescope coated with magnesium flouride with no minimum charge limits. This service should be ordered by sets to expedite handling by the coater, Evaporated Metal Film Corp., 701 Spencer Road, Ithaca, NY 14850.

Many companies don't like to coat lenses made by amateurs. Often the surfaces are not perfect in the fabrication. In coating, the lenses are heated to a high temperature; if a deep scratch or a small chip in the edge is present, the glass can break. Scratches should be reworked; a lens is not considered finished if it has one unless you decide to use it uncoated in the system. If you have a small chip or fracture in the edge of a lens, grind it out with a carbo stone or a piece of metal with 30M size grit.

Workers who take up the art of lens making as part of telescope making will find a new and exciting field of optics. Their new skills will, through new designs, give them a source of unusual and excellent telescopes. Information on lens making is included in this issue.

R.E.C.

■

Build your own...

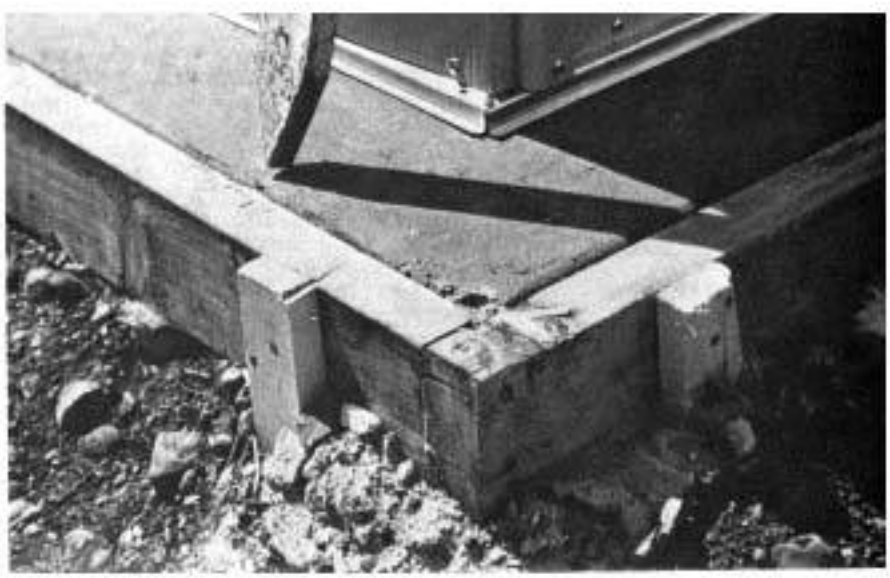
Telescope House

At the tender age of nine, I was taken in hand by my mother as we climbed observatory hill in Washington, D.C. It was a cool September evening. Sounds of late rush hour traffic softened and faded as we passed a sign that said "U.S. Naval Observatory." Through a simple door, we entered a large building with domed roof. An astronomer led us (with a small group of visitors) up an old wrought-iron spiral stairway. At the top was an enormous telescope, the 26-inch refractor used by Asaph Hall in 1877 to discover the moons of Mars. Our astronomer-guide made a few adjustments by turning brass handles on the ends of incredibly long screws on the telescope. He pulled up a ladder and gave me the first look at Saturn. It was and has remained the most beautiful visual image experience of my life. The bright planet with its colorful rings and atmospheric bands was suspended in a black velvet sea. I knew then that someday I must have a telescope for my own use.

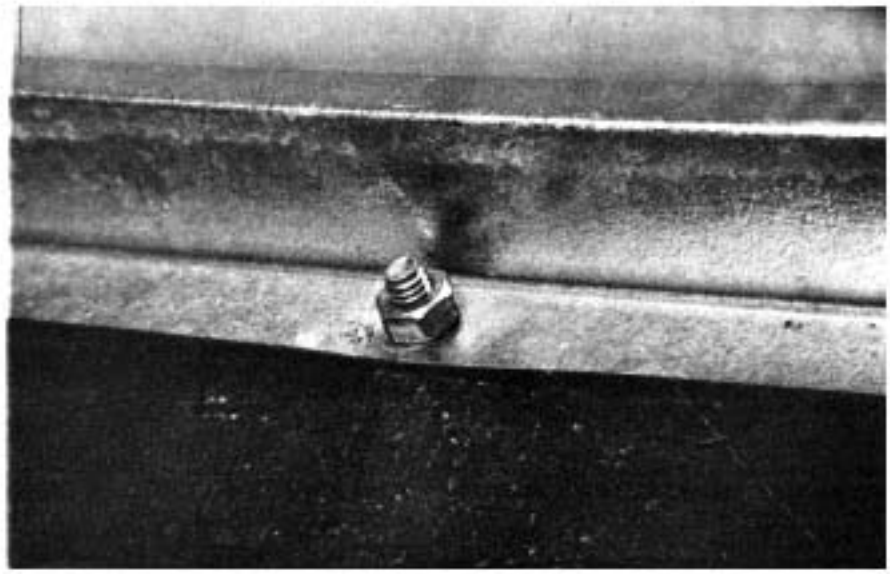
It was many years before that child's dream came true. After 15 years of university education and establishing my business, I finally could afford a modest telescope and the time to use it. Selecting an 8-inch Schmidt-Cassegrain reflector, I quickly found that buying the telescope was the least of my problems. In contrast to the manufacturer's ads, setting up and dismanteling the telescope was a lot of work! When the telescope was not in use, storage was a problem. And the worst problem was polar alignment for astrophotography. The solution to these recurrent, time-consuming problems was to build a small telescope building. This is a description of my building project.

Now if I can build a telescope house, anyone can. The cost totaled about $300; however, a frugal and inventive person could probably reduce that to under $200. In addition to the money, I put in about 20 working hours. The building has held up well through hail storms, blizzards, and winds as high as 90 miles per hour. The design allows easy access, yet it looks like a simple yard tool shed to a stranger, which hopefully will deter theft and vandalism. In any case, if a thief really wants to break in, no design can prevent it, but this design discourages it at a reasonable cost.

Clear and level the ground.



2" x 4" studs serve as concrete forms. The corners are staked to the ground.

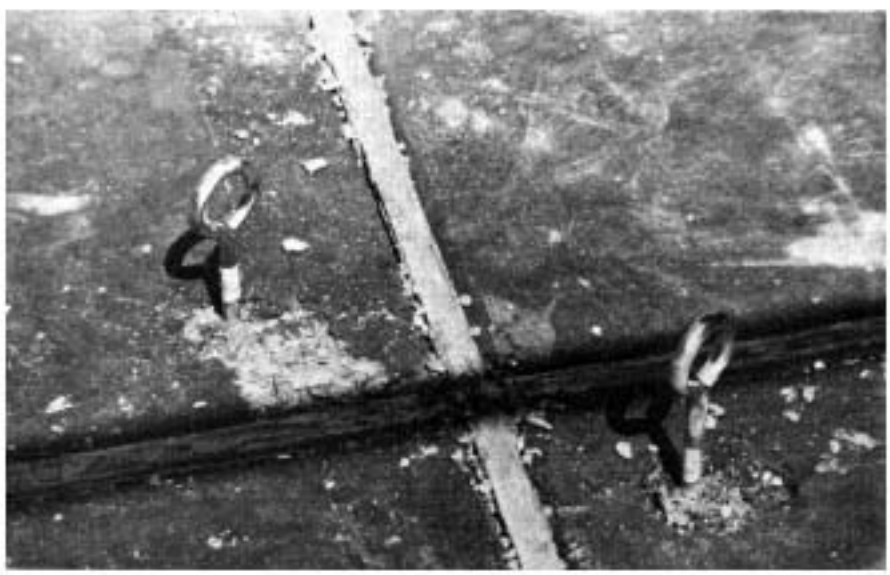


Bolts anchor the shed solidly to the concrete pad.

Fancy domes and slide-back roofs are nice, but they do advertise to every passerby that here is something worth stealing.

Building a telescope house is a matter of compromises and careful planning. First you should locate the building site. The land around my home offered five possible sites. Using a compass, I measured the angles of sky blocked in azimuth and altitude by trees, buildings, and neighboring lights. With the exception of the south sky, I figured any celestial object below 20° altitude would be hard to photograph. Since my house gives off enough heat to cause convection currents, I avoided it and sacrificed that portion of the sky. This narrowed the choices considerably. The final site I chose is near a utility pole, but it gives a view of all the north sky, 2/3 of the south horizon, and all of the sky above 20° altitude.

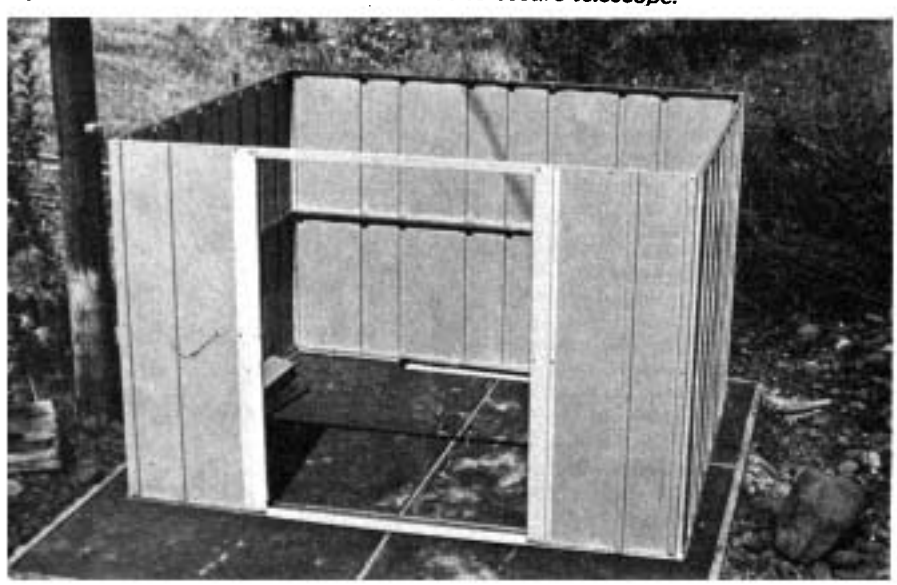
After careful attention to roofing design, I selected the cheapest prefabricated yard shed (Montgomery Ward WAG-4453A) on sale in their catalog. It's proven to be perfect for my needs, but if you have the money, it would be worthwhile to invest in a higher quality structure.



Eye bolts embedded in the concrete serve to secure telescope.

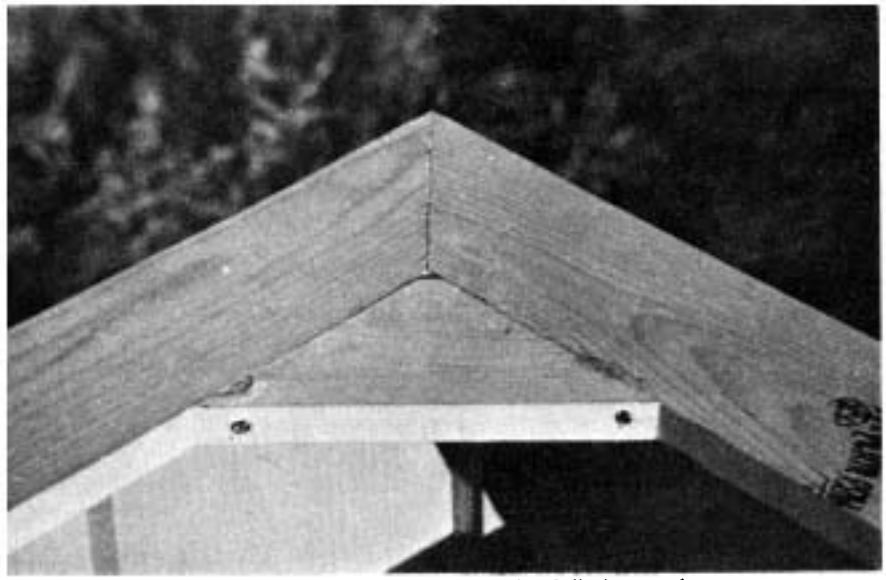
The size of your building is crucial. Seven by eight feet is ideal in some respects, but it is the minimum workable size. Anything larger would have a roof too heavy to lift off, especially when covered by snow. The shed's wall height of five feet provides a comfortable viewing level, protection from wind, and good sky exposure. The doors should be oriented south to provide a view of low altitude stars through the doorway. Today, costs limit building from brick or lumber. Sheet metal now is the cheapest building material.

Once you have located the building site, your first step is to clear the ground of vegetation and level it as much as possible. Gravel up to six inches deep is desirable for drainage (but not essential). Next, prepare a form for the concrete foundation from 2" x 4" lumber. Mine measures 9' x 10'6". Each corner of the form is nailed to a wood stake 16" long, driven into the ground to hold the form in place. I used 1" x 4" lumber to divide the inside of the form into four squares to decrease the risk that the concrete would crack due to expansion and contraction. The



The walls should go up on a windless day.

Telescope House



Rigidify the walls with a sill of 1" x 4" lumber and solidly brace the corners.

dividers can be ripped from 2 x 4s. Should you wish a concrete pier, this is the time to construct the form for it.

Before pouring any concrete, assemble the floor frame and anchoring bolts. The floor anchoring bolts should have a large washer and be tightly secured to the metal floor frame with two nuts.

Now you're ready to pour the concrete. Phone a ready-mix concrete firm and tell them you need a little less than one cubic yard of concrete. Usually the truck can stop by your house on the way to another job for about $30. After the concrete is poured, finish the surface smoothly and set the metal floor frame. Great care must be taken to make the corners of the floor frame square — once the concrete sets there's no going back! Push the anchoring bolts of the floor frame into place allowing 2½ feet from the door opening to the south end of the concrete foundation. If your telescope will be tripod mounted, I'd suggest embedding two large eye bolts in the middle of the floor. Mount large washers on the screw end and push into the wet concrete. Later you can secure the telescope against theft by chaining it to these anchors.

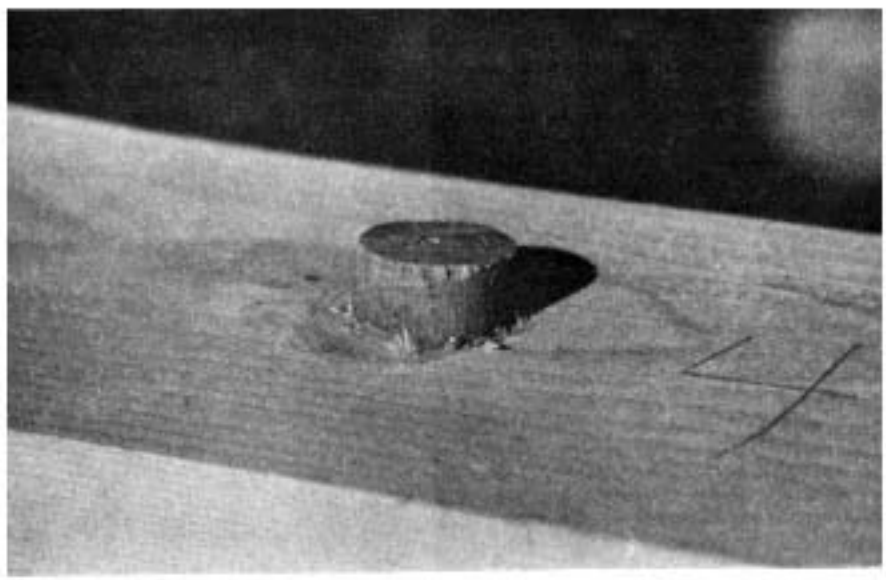
Cover the concrete for three days with a plastic drop cloth. Three times each day, remove the plastic cloth and sprinkle lightly with water. After three days, the concrete will be solid enough that building can proceed.

The instrucions for assembly of the building provided by the manufacturer must be viewed as a rough guide and not specific instructions. I found several errors in the instructions that led me into time-consuming disassembly and reassembly.

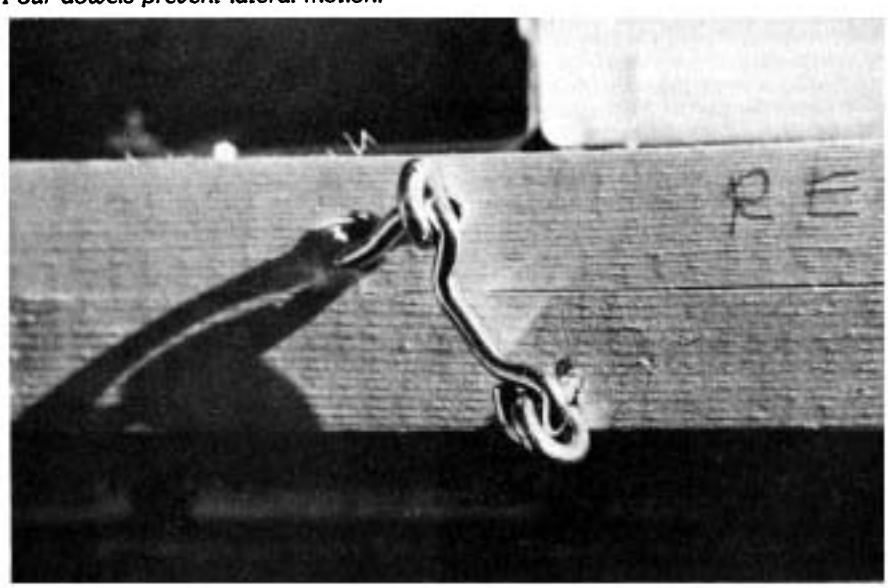
Don't try to assemble the building on a windy day: during the initial assembly, the structure is very susceptible to wind. Having a helper will make the assembly of the sides much easier.

Being able to to lift the roof off the building is the whole trick to adapting a yard shed for your telescope. If you can't remove the roof, you can't use the telescope: The roof design must provide enough rigidity for self-support. I solved this by making two big wood frames similar to large picture frames from 1" x 4" lumber. A carpenter friend made these for me, and nicely braced and glued the corners.

One frame contains four protruding 1" dowels mounted on it. The other frame (the one attached to the roof) sits on top and has



Four dowels prevent lateral motion.



Twelve large hook-and-eyes hold the roof on when the observatory is not in use.

holes matching the dowel pegs. This provides great stability in winds because the roof, if held down, can't slide sideways at all. It also makes it easier to put the roof back on the building at the end of observing sessions.

The lower wood frame is permanently screwed to the metal frame of the building. The upper frame is permanently screwed to the roof assembly. You'll have to add these holes yourself — they never intended their shed's roof to come off. Use screws with very wide heads to prevent leaking of rain and melted snow. Also, it helps to caulk as much as possible. Wax both wood frames heavily to prevent them from freezing together in winter.

Twelve hook-and-eye fasteners such as used for screen doors are mounted inside to hold the wooden frames to each other. This roof would have trouble coming off in any wind short of a tornado. Attach wooden blocks inside the doors, and mount a sturdy hinge latch to hold a key-type lock to secure the sliding doors.

An electrician can be called to place a four plug outlet inside the building. Remember that all outdoor electrical work should be grounded and weather proof. If you don't know how to do electric work, don't try it: this is the wrong step to save money on!

The tripod for the telescope should be adjusted to allow one inch clearance from the center beam of the roof with the telescope folded down. This is comfortable and adequate. I used a masonry drill to make ½" deep holes in the floor for the tripod legs. This set-up has maintained alignment despite my kicking it in the dark many times.

To use the building, I unhook all 12 hook-and-eye fasteners and slide the roof toward the south. I like to rest one end on a small dog house and the other end against the building. It takes me about two minutes to get set up — as opposed to the 30 minutes it used to take without the telescope building. The telescope itself can be covered with a black plastic trash can bag for protection from dust and roof leaks. Triangular scraps of plywood or fiberboard provide me with handy shelves in both north corners of the building.

The reward for all this work is more time to use your telescope. Have fun!

John R. Tkach, M.D.
Educational Trust
Route 4, Box 60
Bozeman, MT 59715

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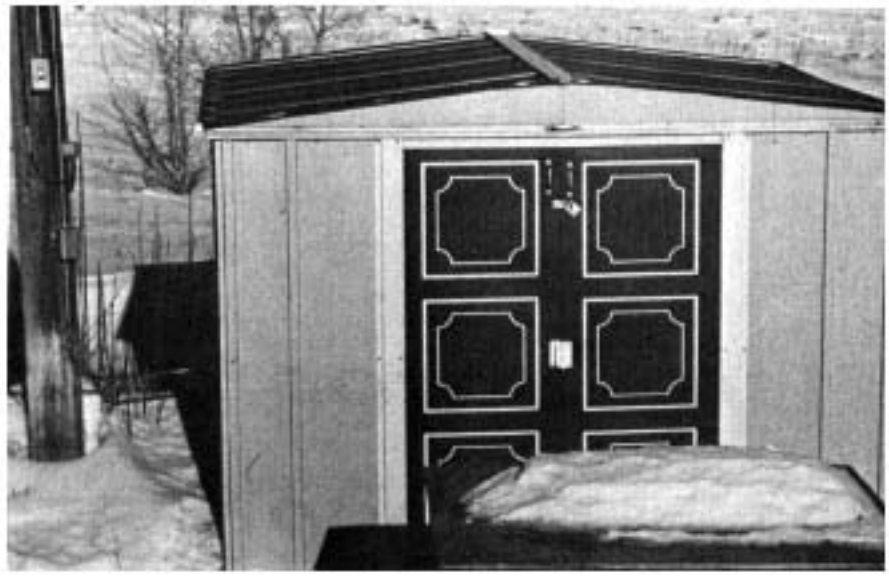
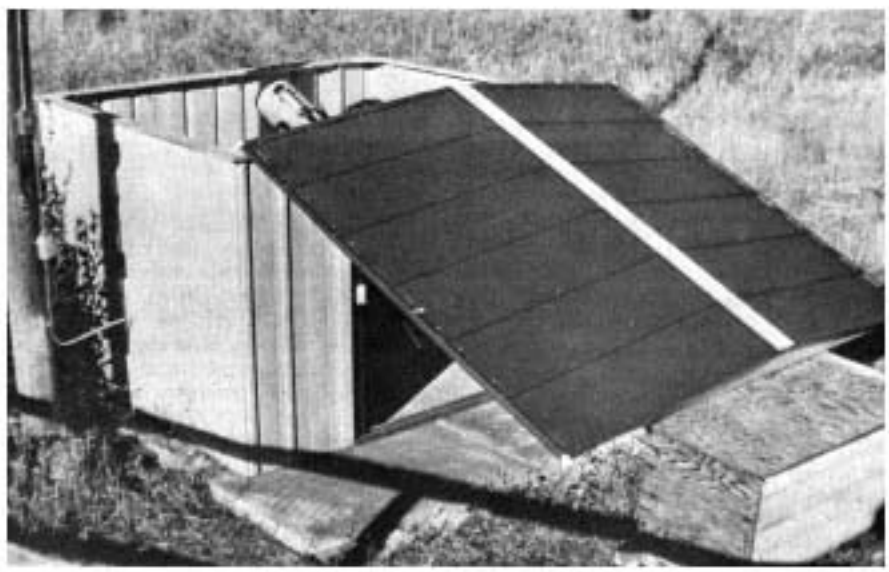
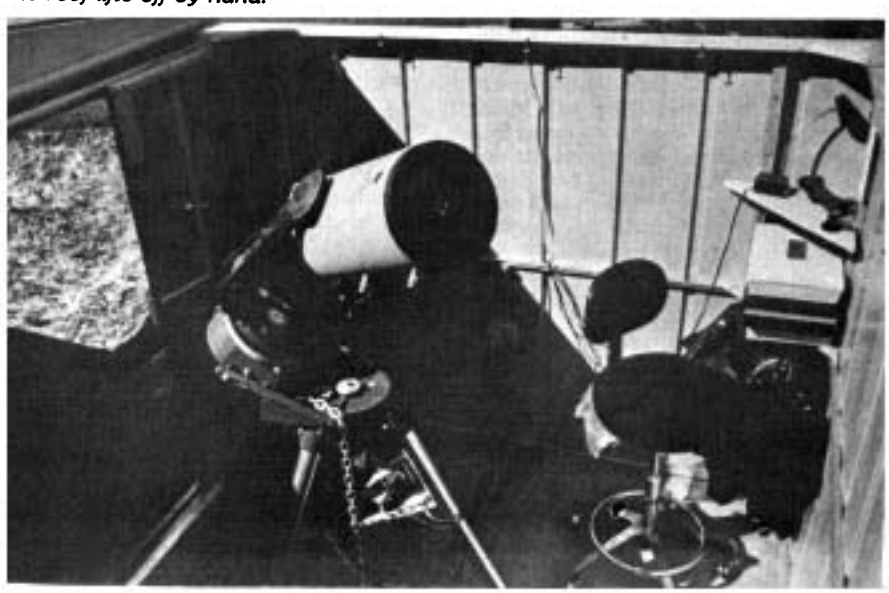


Finished, the observatory looks like an ordinary garden shed.



The roof lifts off by hand.



Inside, the telescope and observer are snug and secure.

A Three Weekend Observatory

The familiar, trying ritual of setting up my telescope and laboriously lining it up on the pole for each observing session finally convinced me that I needed a permanent observing station which could be opened and readied for use in a few minutes. As I am a free-lance photographer by trade, my schedule is erratic and hours are sometimes long. Having my own observatory promised to let me spend more time at the eyepiece or guiding, as well as making weeknights observing nights.

My experiences in constructing my present observing structure, which is actually the second building on my site, may be helpful to other observers. My first building, which was identical in all respects — except in size — to the second one, housed a Celestron 8.

The present structure contains a 12.5-inch f/6 Newtonian, which started out as a Cave 12.5-inch with a focal ratio of f/5.1. I replaced the mirror, spider, and tube with Meade components in order to achieve a longer focal length and a shorter tube-focal plane distance. The original Cave setup produced considerable vignetting despite a 3.1-inch diagonal (which remains), due to a very short tube and extremely high focuser.

This was my own fault, not Cave's. I originally intended this monster of a scope for my first building, and so I ordered everything to keep the tube length short. I thought I could squeeze a 12½-inch scope into a 76" × 76" space. Realizing the error of this decision, I decided to do what I should have done in the first place: get a 12.5-inch f/6 system with a larger building. *Sic transit gloria mundi.*

All this changing of plans and construction and reconstruction resulted in a design which I have found very successful. Best of all, the total construction time for the final building, allowing for concrete setting, was just three weekends! I had so much fun conceiving and implementing this project, with no previous carpentry experience, that I am convinced any equally enthusiastic amateur could do the same. And most important, gone are the setup headaches, the lost time, and the frustrating, constant polar alignment.

Before starting construction, set up your instrument and determine all clearances required. If you own a compact telescope, your primary concerns will be overhead clearance and providing adequate space around the instrument for you to move with comfort. A Newtonian requires much more room, so if you allow adequate wall clearance for the telescope, there will be plenty of room for you and visitors. My building measures 120" square on the outside and provides 110.5" inside.

The 80" tube of the telescope is offset, as is usual in Newtonians, to compensate for mirror weight; however, there is still a good 8" wall clearance in all positions. The roof gives 70" clearance inside at the north, and 58" at the south. Standing upright without scraping your head is only possible at the north end of the building, but the prime function of this design is telescope/accessory protection, and furthermore, the low walls are essential for observation of southern declinations. The closer the roof to the telescope when it is in its storage position, the better.

The work of building the observatory divides itself rather naturally into three segments, each of which, under normal circumstances and good weather, takes about one weekend. On the first weekend, you pour concrete. On the second, you put up the frame. On the third, you build the roof and finish off all the little jobs.

Weekend One

The pier must be totally unmovable. Make it large, especially if you contemplate (or think you might contemplate) a larger telescope. I can tell you that installing 11,000 pounds of concrete through the door of an existing building in order to have a larger pier is not an unexciting adventure, but I don't advise it as a nerve tonic.

You can determine the length of pier pipe necessary by allowing 40" for the hole depth, 12" for the height of the raised floor above ground, and adding the height of the pier off the floor. Remember: keep a Newtonian low to the floor to reduce eyepiece height.

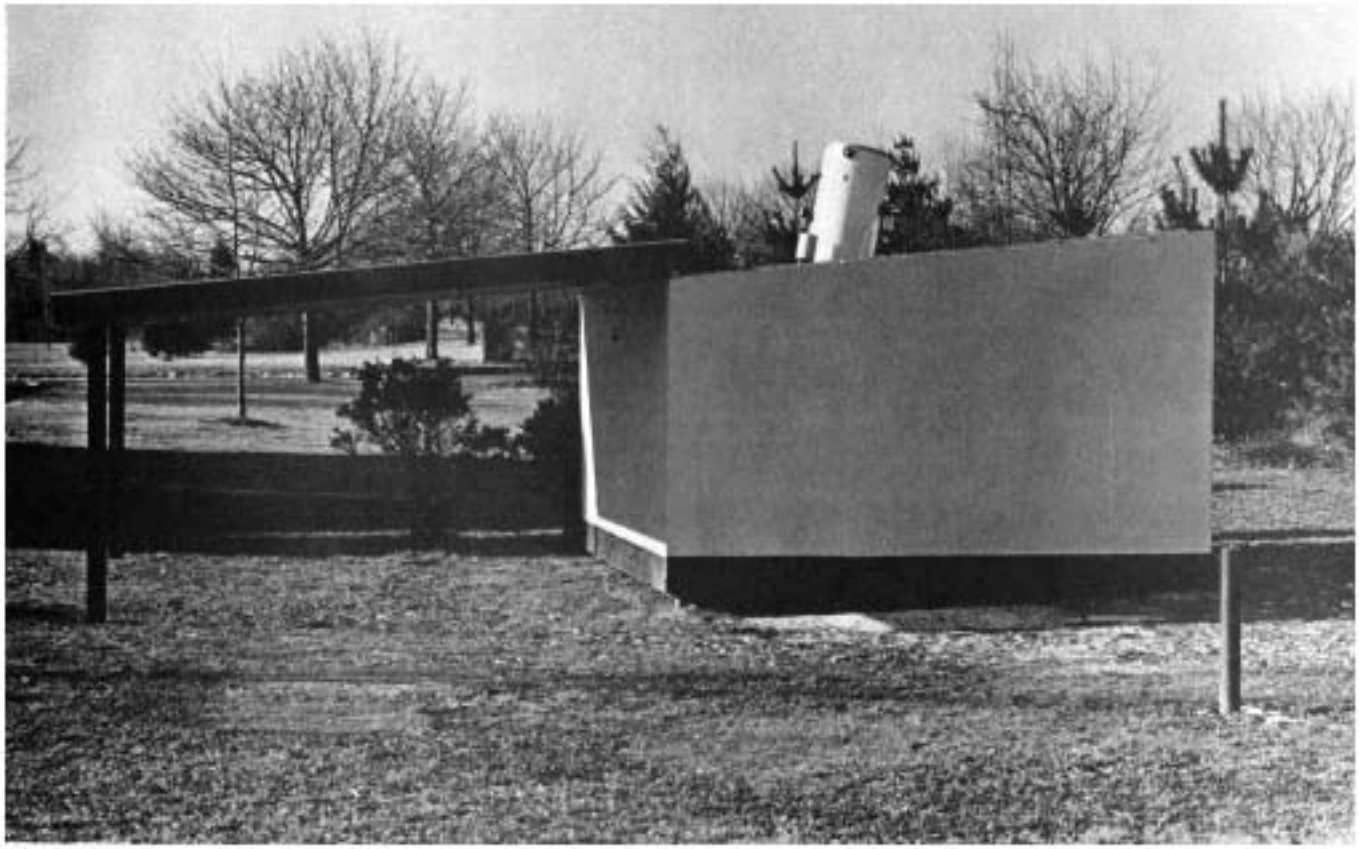
My pier is an 8.5" O.D. steel column 84" long. It is bedded in a block of 4,000 pound test block concrete 40" × 40" × 40". Before my concrete supplier poured the concrete, I added a bed of gravel, horizontal bolts to the pipe to prevent pipe slippage (better safe than sorry), and a cage of steel reinforcing rods for lateral strength. Perhaps this is overkill, but I sleep well knowing that if a runaway truck knocks over my building, the pier will stop it cold. Don't tell my wife this, but I just know I could put a 16" on that pier....

Be sure to fill the pipe with concrete. I didn't at first, and when the pier was struck with a hammer, the telescope vibrated like a tuning fork for three minutes.

While the concrete for the pier is setting, dig four holes for the corner posts which will support the floor and walls. These will be — if you're a traditionalist — aligned with the cardinal directions. Place four 6" × 6" cedar posts in three feet of concrete.

Weekend Two

After the concrete has set and begun to cure, nail a frame of 2 × 10s on the outside of these posts, leveling as you go, so that the top of this frame lies ¾" below the height you have predetermined for the pier above the floor. Run 2 × 8 joists in one direction inside the



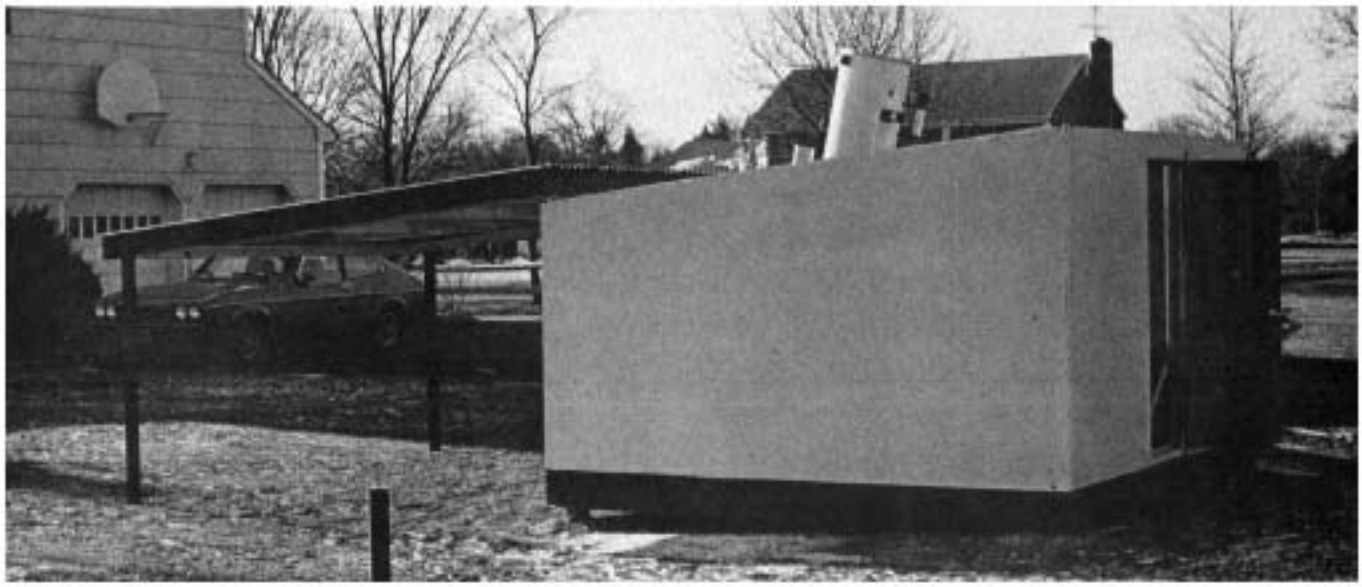
frame, lay a ¾" plywood floor on top of this whole assembly, and nail it down. Cross struts between the 2 × 8 joists are unnecessary: thick plywood is an excellent stabilizer.

You now have a really solid floor, without a lot of concrete forms and leveling. If you leave a little gap about an inch wide all around the pier and fill the gap with foam rubber, a herd of John Travolta fans will not move that pier.

Next, lay a sill of 2 × 4s around the edges of the floor. Then, using this layer of 2 × 4s as a base, put up four corner posts of the proper height, cut at a slant at the top to conform to the slope of the roof. Add 2 × 4 studs (also slanted) every 16" or 24" between the corner posts after you have placed the four top wall "rails." These rails will act as binders and will provide an even mating surface for the roof. A hint: use 2 × 4 inserts at the bottom between the studs instead of toenailing. It's more expensive, but toenailing is insecure, and it's hard to tell how far the stud will move when you hit it from the side before the nails take hold. With the inserts, you can nail in from the side.

Once the frame is complete, use galvanized nails to install the plywood shell. Either ⅝" or ¾" exterior ply is possible, in 4 × 8 sheets. The beautiful part of this operation is that the 4 × 8 sheets of plywood not only act as a square, by helping you keep the whole building true (you'll find yourself having to bend your frame slightly to make the plywood fit), but they also contribute tremendous lateral strength. I can walk along the top of my building's walls, and at 205 pounds I don't produce a trace of wobble.

Finish your doorframe just before you enclose that side of the building in plywood. If



A Three Weekend Observatory

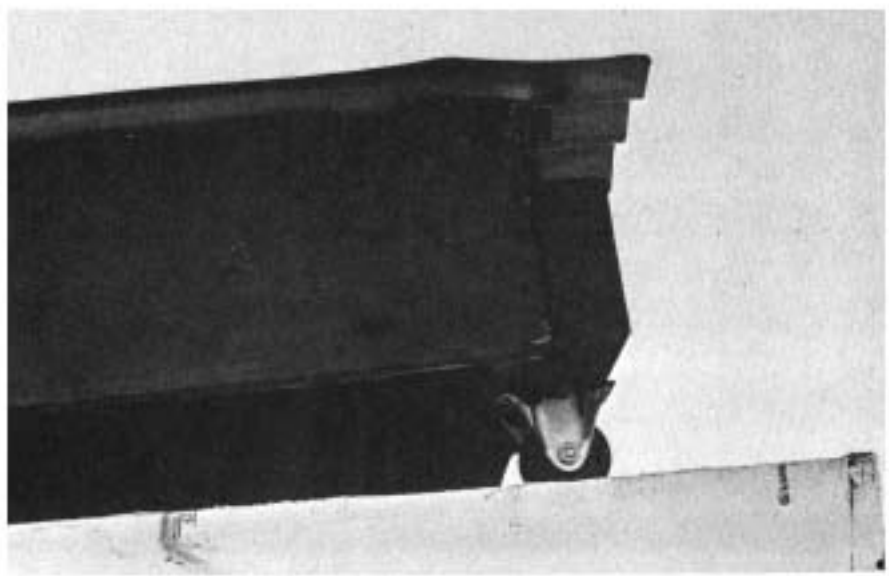
you build the doorframe any sooner, you may discover a change in dimensions when the plywood goes on and the building gets squared-up.

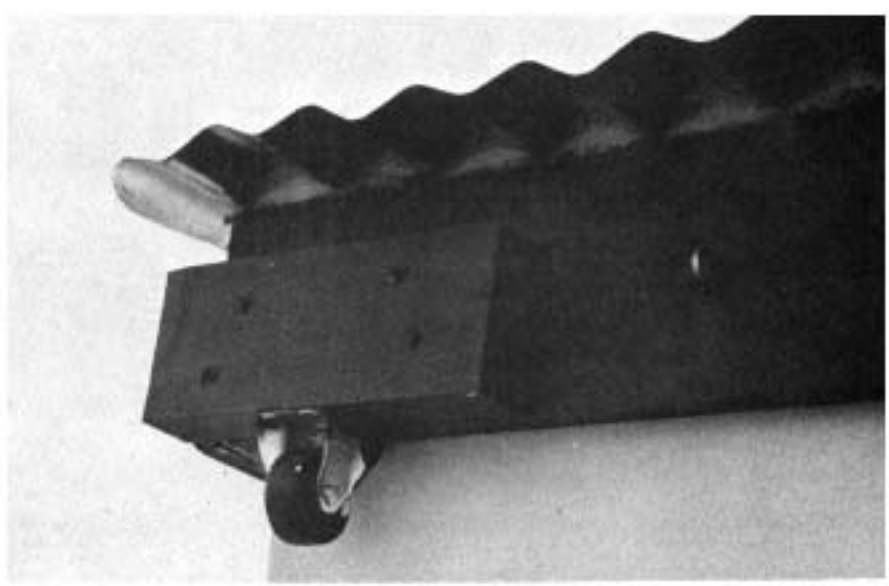
Weekend Three

Aside from detailing and painting, the final step is the roof. Allow a full day to assemble this component, as in some ways it is the least forgiving of error. Although the actual construction time is a few hours, you'll want to take a lot of time to think each step through, and double-check yourself. It isn't difficult, but once the aluminum starts going down, there's no turning back.

I spent many hours thinking about various roof designs, and consulted many reports in astronomical literature, before rejecting all possibilities as too cumbersome, ugly, heavy, or complex. A one-piece, roll-off shoebox style roof was the simplest, but would it be light enough? Worse yet, I didn't see how I could support it once the building was open for observation. I rejected the usual outside support frame seen trailing behind many an amateur building as too ugly. My by-this-time-totally-disgusted-wife concurred. A friend suggested that the roof carry its own supports. Eureka! Keep the whole thing light with corrugated aluminum — expensive, but unbeatable for strength, light weight, and good heat dissipation in the summer. No cooked optics for me!

To get started, measure the final outside dimensions of the top of your building, and then, using long screws throughout (preferably brass), build a frame of 1 × 6 boards with 1" to 2" larger inside dimensions. Install three 1 × 3 cross struts across the width of the frame, that is, across the two sloping sides, and cross-brace them with more 1 × 3s at regular intervals. Screw 4 three foot sections of aluminum tubing (flattened at the ends) to the corners for lateral bracing. Then install 1 × 3 all around the inside of this whole frame, short side against the frame, under the cross-bracing. This will act as a mating surface for the top of the building walls, and works beautifully to keep out rain. (Despite all odds,





rain will climb up under the roof overhang in a high wind.)

Then screw the aluminum sheets, corrugations parallel with the slope of the roof, to the frame and bracing. Seal the overlaps between sheets with silicone or caulking before installation, and also use sealer to waterproof the sponge rubber sealing strip supplied for the ends of the corrugated sheets.

Find a strong friend, say a prayer, and lift the roof on the building. Install hasps and padlocks at two ends, handles for lifting at the high and low sides, and add casters to blocks screwed to the high side of the roof frame, spaced the same as the tops of the side walls. Cut a small channel at the rear of the side walls, and add two stilts to the rear of the roof. With a little muscle, you'll be able to lift the front of the roof up and put the wheels on the tops of the side walls. Then go around to the back of the building, and slide the roof down the walls until the building is open. A small strip of wood on the inside lip of each side wall prevents the wheels from slipping off the track.

The bulk of the work is done. Installation of a door, several coats of paint, and perhaps a nice rug for the floor will finish off the project. Now the fun begins: your observatory will enable you to have everything at your fingertips, laid out as you choose. Storage and transportation will cease to be a problem. You're entering a whole new realm of amateur observation, as unlike field trips as a yacht is to a skiff. And you'll never want to go back.

Total the work up now, and you'll realize that your own version of Kitt Peak is, at most, three weekends away!

John W.H. Simpson
366 Gallup Road
Princeton, NJ 08540

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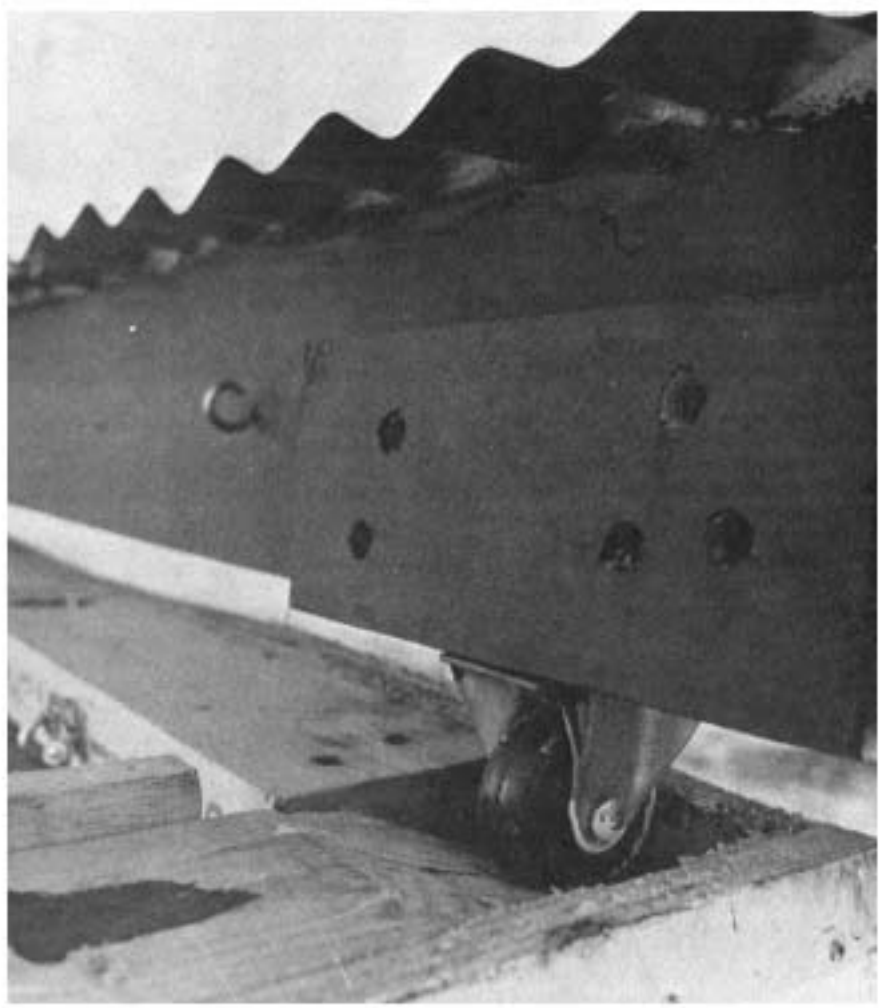


Apollo Observatory's 19⅜" Dall-Kirkham Telescope

Amateurs and Museum Unite in Cooperative Effort

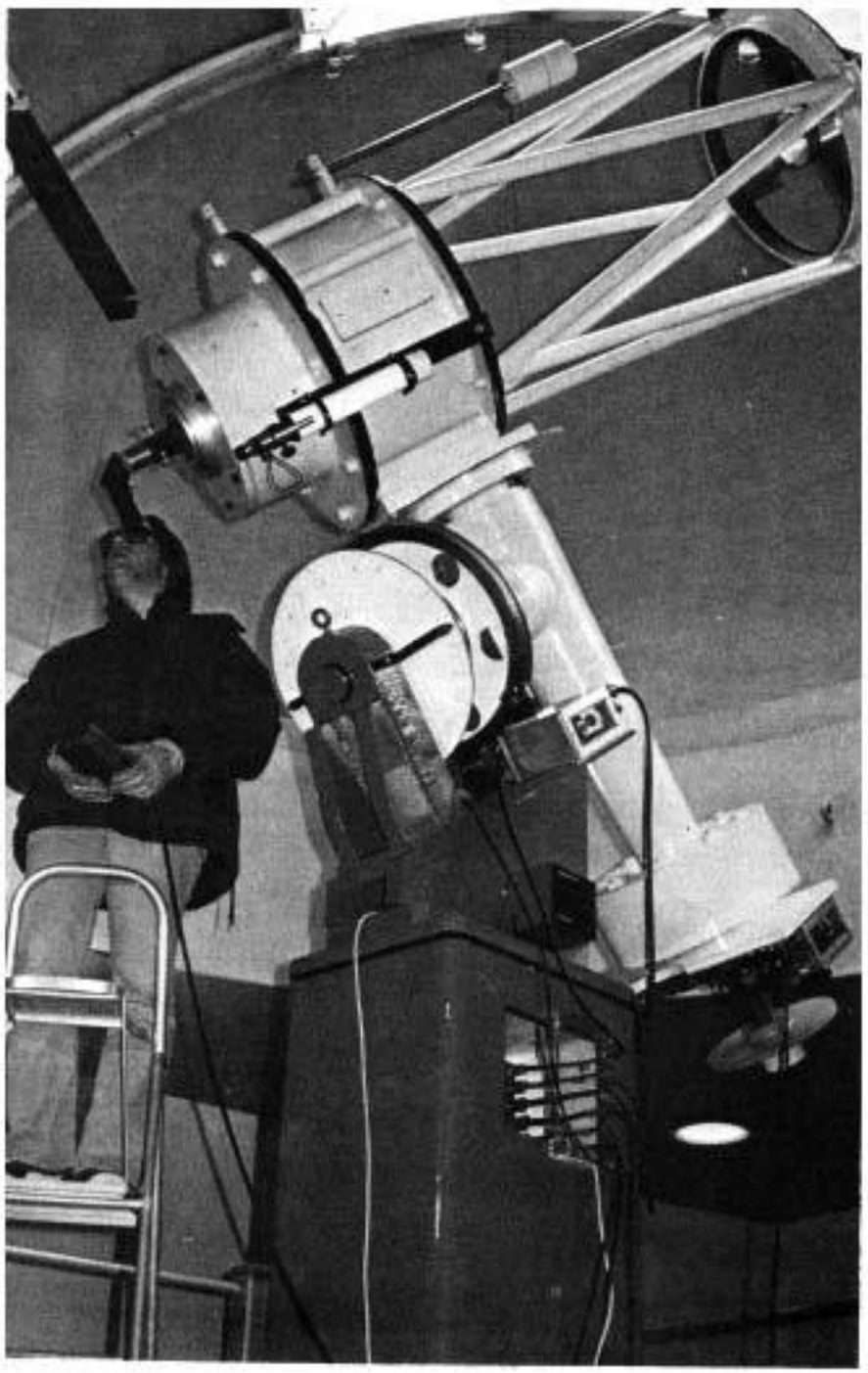
The Miami Valley Astronomical Society and the Dayton Museum of Natural History have cooperated with programs and shared facilities for amateur astronomers and TMs since the 1950s. After Operation Moonwatch, an unsuccessful attempt to house their telescope in a county park near the city, the Society joined the Museum in a cooperative effort to design and operate a large amateur observatory facility. Funding for the building was provided by two local foundations, and, in 1968, the building phase of the project was completed.

The two-story building contains a meeting room, a lobby and display area, a radio room for the Dayton Amateur Radio Association, and three telescope making rooms plus an office for the M.V.A.S. The dome room was located on the second floor, isolated from the building air-conditioning system with thermal pane windows and door gaskets, and topped by a 16-foot fiberglass dome. The 3-foot diameter steel and concrete pier to support the telescope was built to the level of the dome floor and is isolated from the building. The telescope pier itself, made of steel, sits atop the concrete one.

The design and fabrication of the telescope was the responsibility of the M.V.A.S. Two donations went a long way toward determining the size and type of the instrument. First was the donation of the mounting: an almost exact copy of the University of Toronto 19-inch telescope described in **A.T.M. Book 2**. It was donated by the owner of a local tool and die company.

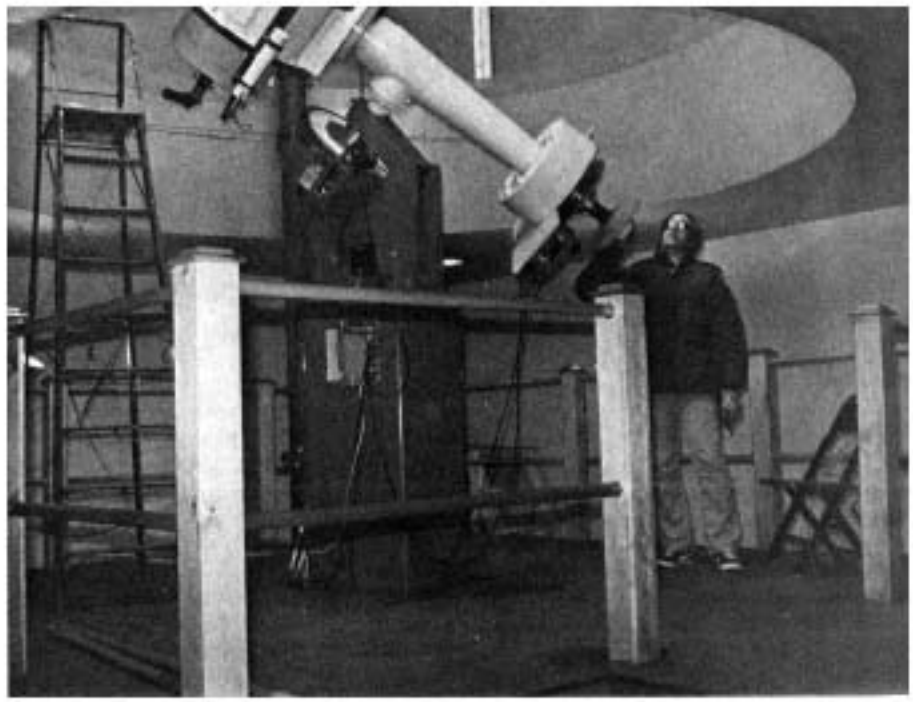
Second was a rough block of GE fused silica. This material became the primary mirror, with a diameter of 19⅜ inches.

A catadioptric relay system was chosen for the optical system. An advanced mirror and lens maker in the M.V.A.S. at the time probably could have fabricated the optics and brought the system to completion. Unfortunately, he died of a heart attack before completing the primary. Eventually, the optics were completed professionally. The painstaking job of designing all the mechanical components was undertaken by many M.V.A.S. members, and all fabrication was donated by local tool and die companies.



View from the southeast side of the dome room. Because the telescope was raised "to permit easier viewing from the meeting room below", it's more difficult to view through the telescope — a high ladder is needed.

From the entrance to the dome room, you see a three-foot platform built around the instrument. Note the safety railing and tall ladder used for observing.



A contribution by another local foundation provided the money necessary to purchase a custom drive and control system from Edward R. Byers. Eventually, all the parts were completed and the system was assembled. However, the combination of a very rigid, but difficult to adjust mounting, with the tight tolerances required to space and align the optical elements, proved to be too difficult for our group.

After eight years of struggle, we decided to abandon the catadioptric system. We planned to refigure the primary and generate a new secondary mirror to make a classical Cassegrain optical system that would fit the telescope with very little mechanical redesign. But after two attempts to reach the desired paraboloidal figure on the primary, we found that a flaw in the blank would make it impossible. A Dall-Kirkham system, however, turned out to be possible, so in the end we had Custom Optics of Tucson, Arizona complete the optics for the redesigned instrument.

By December 1977, we were once again ready to assemble and align the instrument. This time everything worked. The telescope now has a 19.37″ primary with an 80.3″ focal length. The secondary is 5.8″ in diameter with a focal length of -32.9″, giving an effective focal length of 285″ (about f/15) with a final focal plane 27.5″ behind the primary.

Since the Apollo Observatory is located only about one mile from the center of Dayton, the site has considerable light pollution even on the best of nights. However, we knew this when we planned the facility — a public use, educational telescope cannot be successful if the people can't easily reach it. Also the money for the project was donated in order to benefit the people of Dayton.

We are constructing baffles to keep the field as dark as possible, but we will certainly never see the maximum performance from our optics. On the other hand, thousands of people will have the thrill of observing with a large telescope — and that we must remember was the aim of the project.

Although our project was originally intended to take two or three years, it ended up taking more than a decade to complete. Today, however, we and the citizens of Dayton have a large usable instrument which the public and the amateur can use and enjoy.

When the 19-inch instrument project began, we also instituted a Midwest "Stellafane," the Apollo Rendezvous and Telescope Fair. The big telescope was the nucleus of interest, but the meetings also included amateur and professional talks, astronomical displays, exhibits, a flea market, and seminars. The meetings are always held on the second weekend in June; the 1979 gathering will be June 9 and 10.

Exhibits at the 1978 meeting included the largest number of telescopes ever, and gave TMs a chance to show many innovations for the benefit of those attending. In this spirit, there are no prizes except a Certificate of Merit awarded to exhibits that have most contributed to the knowledge of those attending. Traditional "contests", we feel, place too much emphasis on the cost and size of displays and instruments, and foster jealousy rather than the sharing of knowledge and pleasure in a hobby.

Roger Hoefer
Dayton Museum of Natural History
2629 Ridge Avenue
Dayton, OH 45414

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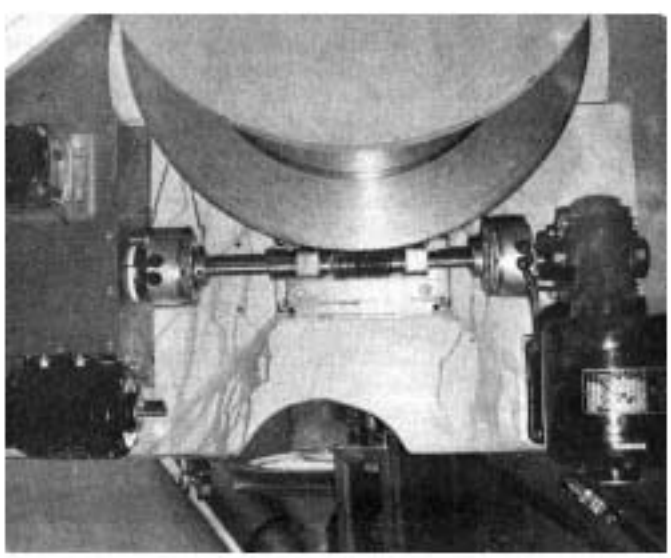
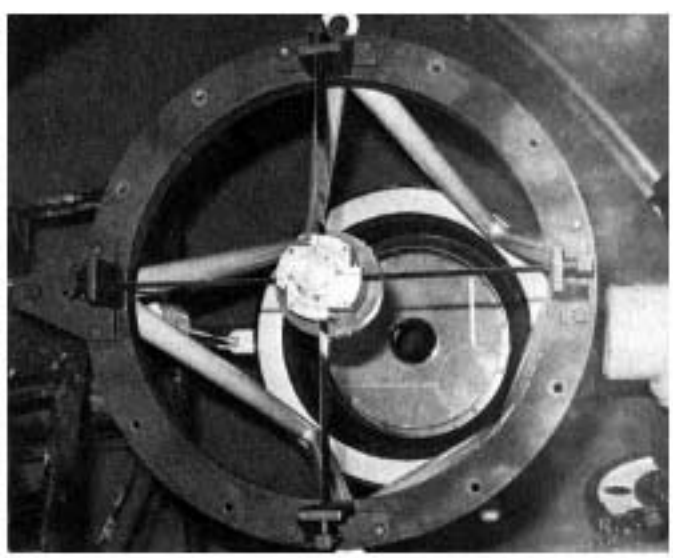
Left: The declination axis drive system, showing the 20-inch aluminum gear and stainless steel drive worm, uses separate slew and set motors. Note magnetic clutches on shaft. Right: The four vane spider and secondary mirror cell. The cell is mounted on a radius which permits an unlimited number of different adjustment angles.





Description of a Forty-Feet Reflecting Telescope. By Wm. Herschel, LL.D., F.R.S., discoverer of the Georgium Sidus

How I Came to Build the Forty-Feet Telescope

It will be necessary to mention a few circumstances that led the way to the construction of this large instrument, in the execution of which 2 very material requisites were necessary: namely, the support of a very considerable expense, and a competent experience and practice in mechanical and optical operations. When I resided at Bath I had long been acquainted with the theory of optics and mechanics, and wanted only that experience which is so necessary in the practical part of these sciences. This I acquired by degrees at that place, where in my leisure hours, by way of amusement, I made for myself several 2-feet, 5-feet, 7-feet, 10-feet, and 20-feet Newtonian telescopes; besides others of the Gregorian form, of 8 inches, 12 inches, 18 inches, 2 feet, 3 feet, 5 feet, and 10 feet focal length. My way of doing these instruments at that time, when the direct method of giving the figure of any of the conic sections to specula was still unknown to me, was, to have many mirrors of each sort cast, and to finish them all as well as I could; then to select by trial the best of them, which I preserved; the rest were put by to be re-polished. In this manner I made not less than 200, 7-feet; 150, 10-feet; and about 80, 20-feet mirrors; not to mention those of the Gregorian form, or of the construction of Dr. Smith's reflecting microscope, of which I also made a great number.

My mechanical amusements went hand in hand with the optical ones. The number of stands I invented for these telescopes it would not be easy to assign. I contrived and delineated them of different forms, and executed the most promising of the designs. To these labours we owe my 7-feet Newtonian telescope-stand, which was brought to its present convenient construction about 17 years ago; a description and engraving of which I intend to take some future opportunity of presenting to the Royal Society. In the year 1781, I began also to construct a 30-feet aerial reflector; and after having invented and executed a stand for it, I cast the mirror, which was moulded up so as to come out 36 inches in diameter. The composition of my metal being a little too brittle, it cracked in the cooling. I cast it a second time, but here the furnace, which I had built in my house for the purpose, gave way, and the metal ran into the fire. These accidents put a temporary stop to my design, and as the discovery of the Georgian planet soon after introduced me to the patronage of our most gracious King, the great work I had in view was for a while postponed.

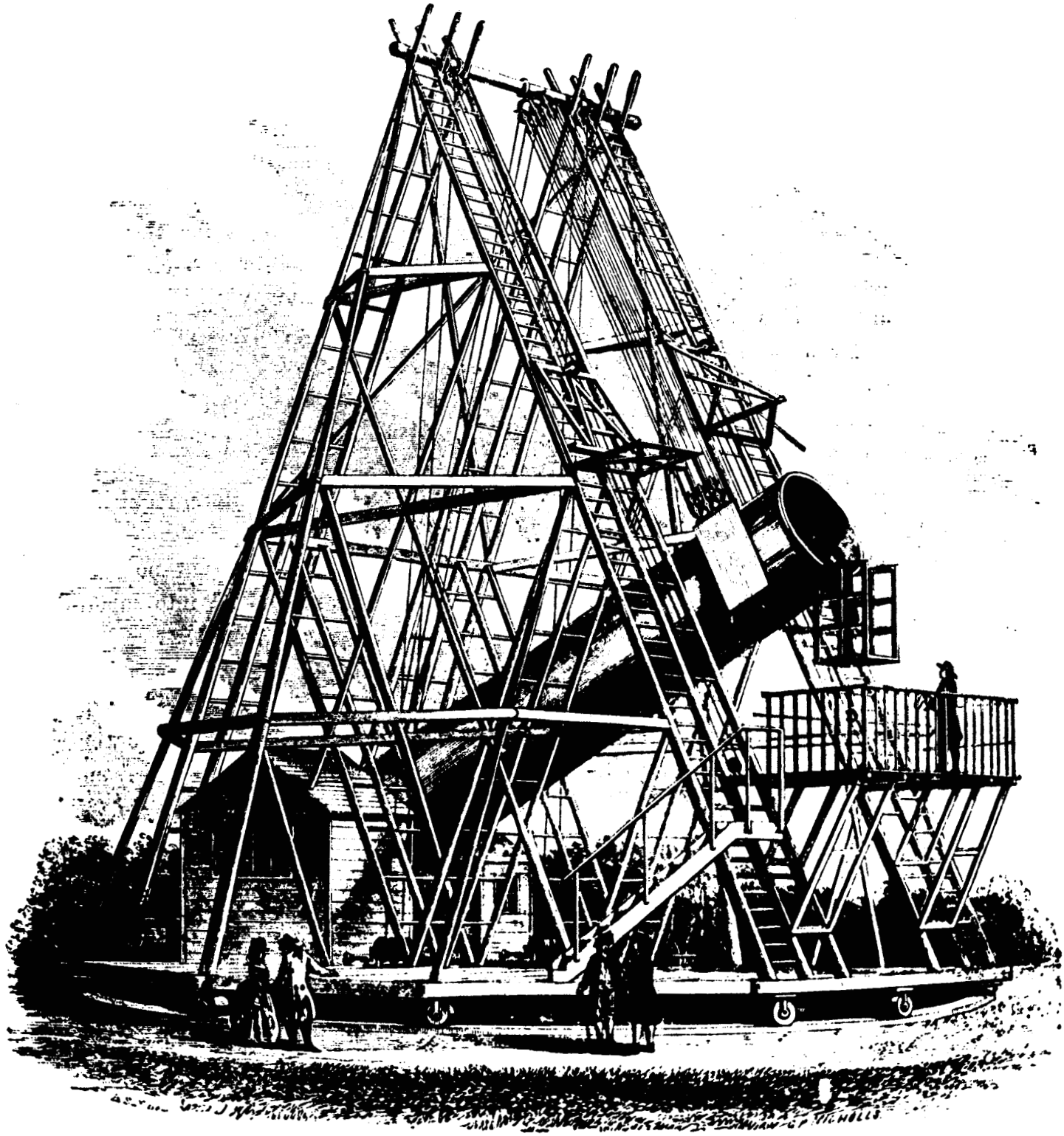
In the year 1783, I finished a very good 20-feet reflector with a large aperture, and mounted it on the plan of my present telescope. After 2 years observation with it, the great advantage of such apertures appeared so clearly to me, that I recurred to my former intention of increasing them still further; and being now sufficiently provided with experience in the work I wished to undertake, the President of our R.S. had the goodness to lay my design before the King. His Majesty was graciously pleased to approve of it, and with his usual liberality to support it with his royal bounty. In consequence of this arrangement I began to construct the 40-feet telescope, which is the subject of this paper, about the latter end of the year 1785. The wood-work of the stand, and machines for giving the required motions to the instrument, were immediately put in hand, and forwarded with all convenient expedition. In the whole of the apparatus none but common workmen were employed, for I made drawings of every part of it, by which it was easy to execute the work, as I constantly inspected and directed every person's labour; though sometimes there were not less than 40 different workmen employed at the same time.

While the stand of the telescope was preparing I also began the construction of the great mirror, of which I inspected the casting, grinding, and polishing; and the work was in this manner carried on with no other interruption than what was occasioned by the removal of all the apparatus and materials from Clay-hall, where I then lived, to my present situation at Slough. Here, soon after my arrival, I began to lay the foundation, on which by degrees the whole structure was raised as it now stands; and the speculum being highly polished and put into the tube, I had the first view through it on Feb. 19, 1787. I do not however date the completing of the instrument till much later; for the first speculum, by a mismanagement of the person who cast it, came out thinner on the centre of the back than was intended, and on account of its weakness would not permit a good figure to be given to it. A second mirror was cast Jan. 26, 1788; but it cracked in cooling. Feb. 16, we re-cast it with particular attention to the shape of the back, and it proved to be of a proper degree of strength. Oct. 24, it was brought to a pretty good figure and polish, and I observed the planet Saturn with it. But not being satisfied, I continued to work upon it till Aug. 27, 1789, when it was tried on the fixed stars, and I found it to give a pretty sharp image. Large stars were a little affected with scattered light, owing to many remaining scratches in the mirror. Aug. 28, 1789, having brought the telescope to the parallel of Saturn, I discovered a 6th satellite of that planet; and also saw the spots on Saturn, better than I had ever seen them before, so that I may date the finishing of the 40-feet telescope from that time.

Foundations, Uprights, and Superstructure of the Forty-feet Telescope

The engraving represents a view of the telescope in a meridional situation, as it appears when seen from a convenient distance by a person placed towards the south-west of it. The foundation in the ground consists of 2 concentric circular brick walls, the outermost of which is 42 feet in diameter, and the inside one 21 feet; these measures are reckoned from the centre of one wall to the centre of the other. They are 2 feet 6 inches deep under ground; 2 feet 3 inches broad at the bottom, and 1 foot 2 inches at the top; and are capped with paving stones about 3 inches thick, and 12¾ broad. These walls were brought to an horizontal plane by means of a beam turning on a pivot fixed in the centre of the circle, which had a roller under it at the end. On this beam and over the roller was fixed a spirit level, to point out any defect in the walls; and by correcting every inequality that could be perceived, they were by degrees brought to be so uniformly horizontal that the beam would roll about every where on them without occasioning any alteration in the bubble of the spirit level.

The length of the ladders is 49 feet 2 inches, and their construction is as follows. The top of each step is 9 inches from that of the one below it; and, beginning 12 inches from the bottom, there are two rounds and one flat placed alternately, as far as 40 rounds, and 19 flats. In the place of the 20th flat is the centre of the meeting of the front and back sets of the ladders; above this is another flat, with a termination of 16 inches at the top. The timber ➤



Sir William Herschel's Forty-Foot Telescope

of the sides being tapering, a similar diminution of the flats and rounds has been attended to, especially as their size, in proportion to the sides, is far above what is generally used in building ladders. The flats and rounds are all made of solid English split oak.

The two outside divisions of the ladders serve for mounting into the gallery, and therefore contain rounds as well as flats. The distance of the sides, the flat parts of which, as in common ladders, are put facing each other, is 18 inches, and remains the same up to the end. But the two inside divisions, which have no rounds, are placed with the flat face outwards, and the distance between these faces being 2 feet 8 inches up to the top, the parallelism of these divisions is preserved outside, while that of the mounting ladders is continued within. The reason of this arrangement is, that the brackets which support the moveable gallery rest on the inside frames of the ladders. These go upon 24 rollers, 12 of them confining the gallery sideways, while the other 12 support it, the parallelism was of course required where it is placed. The mounting ladders are made parallel within, that a moveable chair, intended to be made if required, might be drawn up with a person seated in it, to prevent the fatigue of mounting, or take up in safety any one who chanced to be afraid of ascending an open ladder.

The back set of ladders is constructed like the front; and, the ladders being of the same length, the only difference is that no rounds have been put into them. The flats have been preserved on a double account; first, that the connection of all the side timber might be firm and strong; and secondly, that every part of the frame might be accessible. For by means of these flats we have steps of 27 inches, which may be ascended with tolerable ease, when occasion requires. The method of joining the front and back at the top, is by passing one set of ladders through the other so as to embrace it; the backs therefore, which go outside, are placed a little farther asunder than the fronts; and the same pins pass through them both. The last flat was put into the ladders after they had been erected and secured together.

The middle top cross-beam is placed above the two sets of ladders in the angle made by their crossing each other. The method of keeping it there, and securing the proper distance of the ladders by this beam, which is of a cylindrical form, is as follows: 12 iron loops, shaped to the ends of the ladders, with arms to them like lamp-irons, and a hole at the end of each arm, are slipped down on the ends of the ladders, till 2 and 2 of them meet in the middle of the cross-beam, which is about 8 inches in diameter. Here a screw bolt, coming up through the beam, passes into the holes of the 2 irons, where all is screwed firmly together. By this means no holes are made to weaken the tapering ends of the ladders, and the centre beam takes firmly hold of every one of them; so that were even the pins pulled out, the ladders would still remain firmly kept together.

Besides these there are 3 sets of braces, which serve to confine the poles to their stations. The highest set meets the side brace at the 15th flat. The next meets the middle brace at the 10th flat, and both these make with the side braces a triangle, in the vertex of which is inclosed the large pole that is braced by them. At the 5th flat a third set of braces, which incloses the two small poles as well as the large one, is carried round with 4 divisions. The front of the ladders, it is very evident, would admit of no brace, and is left entirely open for the tube of the telescope to range in. It receives however some confinement from the moveable gallery, which is always hung

across the front, in the place where observations are to be made.

The gallery consists of 3 separate parts: 2 double side brackets with a small platform on them, and a middle passage. The whole of it when joined together is properly railed in at the front by wooden palisades; and on the inside by light iron-capped bars. Each of the brackets by which the gallery is supported consists of 3 frames; a parallelogram for the bottom, with 2 triangular sides erected on the former, and held together by a narrow platform on the top. On the platform are fixed palisades, which turn the corner at the front, and are continued so as to meet the middle platform of the gallery. The palisades are strengthened and rendered steady, by a seat which is fastened against them, and supported from the floor by slight iron bars.

There is a small stair-case by which we may ascend into the gallery, without being obliged to go up any ladder; and as that is strong enough to hold a company of several persons, and can afterwards be drawn up to any altitude, observations may be made with great conveniency; the activity of an astronomer however will seldom require this indulgence. The readiness with which I ascend the ladders, has even prevented my executing the projected running chair, which may easily be added, to take a single person into the gallery after it has been already drawn up to its destined situation. A view of the stair-case in the figure will suffice to point out its construction. I ought only to observe, that in the engraving the gallery is placed higher than where it will join the stair-case properly, but that when it is lowered on purpose, it becomes then to be just one step above the little landing-place of the stair-case, and the palisades of the former unite with the railing of the latter.

The Tube of the Forty-feet Telescope

The next piece to be described, is the tube of the telescope. This, though very simple in its form, which is cylindrical, was attended with great difficulties in its construction. No one will wonder at this who considers the size of the tube, and the materials of which it is made. Its length is 39 feet 4 inches; it measures 4 feet 10 inches in diameter, and every part of it is of iron. On a moderate computation, the weight of a wooden tube must have exceeded an iron one at least 3000 lb.; and its durability would have been far inferior to this of iron. The body of the tube is made of rolled, or sheet iron, which has been joined together without rivets; by a kind of seaming, well known to those who make iron funnels for stoves. The whole outside was thus put together in all its length and breadth, so as to make one sheet of nearly 40 feet long, and 15 feet 4 inches broad. The tools, forms, and machines, we were obliged to make for the construction of the tube were very numerous. For instance, in the formation of this large sheet, a kind of table was built for its support, which grew in size as the sheet advanced, till when finished, it was as large as the whole of it. In the formation of the sheet, cramping irons, seaming bars, setting tools, and claw-screws, were made in great number, to confine and stretch the parts as they were seamed together. The small single sheets of which this large one is composed, are 3 feet 10 inches long, and about 23½ inches broad. Their thickness is less than the 36th part of an inch; or, what will be a more precise measure, a square foot of it weighs about 14 oz. They are joined so, that the middle of a whole one always butts against the seam of the preceding 2, in the manner of brick-work, where joints are crossed by bricks above and below.

When the whole sheet was formed, which was done in a convenient barn not far from my house, the sides were cut perfectly parallel, and afterwards bent over at the ends in contrary directions, to be ready to receive each other. A number of broad hooks, such as were proper for grasping the sides of the sheet, with loops at the other end for cords to go through, were now prepared with their necessary tackle. 12 pulleys were fastened about 11 feet high, on moveable beams, that might be drawn together; 6 on each side. The sheet was now taken up, by occasioning all the

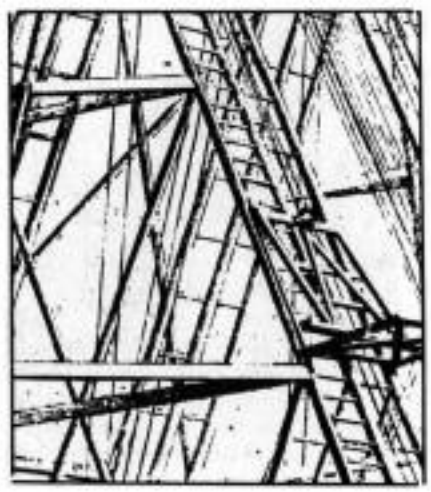
corded hooks to be drawn at the same time, and while it was kept suspended our large table was taken to pieces. Another kind of support was now put under the middle of the sheet to receive it. The form of this was that of a hollow segment, or quarter of a cylinder, cut lengthways, to the extent of a few feet more than the length of the intended tube; and the concavity of which was formed by the same radius as that of the tube.

The sheet being let down, it rested on the hollow gutter; for so we may call the machine that was placed under it. Six moveable wooden segments of a whole cylinder, or circular arches, about 3 feet wide each, which had been prepared, were now brought on the sheet, and placed at proper distances from each other. The sheet was pressed down on the foundation by these, so that no injury could be done by walking on it. The beams which held the pulleys were now brought close together; which being done, we hung the pulleys of one on the hooks of the other beam, so as by that means to cross the cords which held the sheet. In this operation we slackened only one of the cords at a time, the rest being sufficient to keep the whole up. The beams were now again separated, and the cramping hooks by the crossing of the cords drew the 2 sides of the sheets together. When all this was properly arranged, and the arches lowered, the 2 sides of the sheet were gradually brought to take hold of each other. As we proceeded, the wedges within the arches were forced in successively, till at last, with much care and considerable difficulty, the 2 sides completely embraced each other, and were kept stretched by the swelled inside arches.

Another circular arch, closed in with boards all around, well rounded off, and only about 2 feet 3 inches long, had a vacancy at the top into which we could introduce the iron seaming bars for indenting, and for closing up the long seam of the 2 sides. This arch also had its stretchers for swelling it up, and served at the same time, as soon as the seam was properly closed, to beat with mallets the whole sheet all around on its well-finished outside, in order to take away any accidental bulge which it might have received in the long preparations it had undergone, till it came to the present state. The same arch, as soon any portion of the tube had been done, was removed to another place, and the whole was by this means completely seamed up.

The theory on which the strength of so thin a cylinder of iron is founded, is, that the sides of it must unavoidably support it, provided you can secure the cylindrical form of the tube. It appeared to me the most practical way to obtain this end by the following contrivance. By a few experiments I found that a slip of sheet iron, a little thicker than the tube, and doubled to an angle of about 40 degrees, might afterwards be made circular. The deepest we could conveniently bend, and such as I supposed would answer the end, was when the sides were about 2½ inches broad. They were shaped red-hot on a concave tool, which had the required curvature and angle of the slips. The pieces were long enough to form a complete quadrant of the circle, with the ends sufficiently projecting to be seamed together.

Before they were joined the sides received another bending, which was given them by tools of a proper convexity. A back was next prepared, consisting of a slip of iron turned up at both sides, and also bent to the circle. Last of all, the 4 quadrants having been put together, and a back put round them, the whole was firmly seamed together, so as to resemble a hollow triangle bar made into a hoop or ring, of a proper diameter to go closely into the tube, so as to keep it extended, and braced to the cylindrical form. One of these rings was put into the middle of every one of the small sheets, which brought them to about 23 inches from each other. They were carried in edgeways, and



afterwards turned about and forced into their respective places. In order to get them in, as they were all obliged to go in from one side, there was substituted, instead of the circular arches, a kind of temporary props, that could be easily removed, one at a time, and were narrow enough to pass through the hoops while they advanced; and as soon as a ring was in its proper place, no further support became necessary. In this manner we secured the cylindrical form of the tube; and as soon as this was accomplished, we had every thing removed from within and without, and began to give the tube 3 or 4 good coats of paint, inside as well as outside; in order to secure it against the damp air, to which it was soon to be exposed.

As the tube was now much lighter than it would be hereafter, we transported it into my garden in the following manner. Many short poles, about 5 feet long each, were joined two and two by a piece of coarse cloth, such as is used for sacks, about 7 feet long each. This, being fastened in the middle, left at each end part of the pole to serve as a handle for a person to hold by. The cloth of one of these being put under the tube, there was left one of the poles at each side, and 4 men taking hold of the ends of the poles, might conveniently assist in carrying the tube. When six sets of these were put under the tube, it was with great facility lifted up by 24 men, who carried it through an opening made at one end of the barn. The inclosure of part of my garden having also been taken down, with some trees that were in our way, it was safely landed on the grass-plot; where a proper apparatus of circular blocks was put under to receive it. While it remained in this state, we prepared every thing for its reception, and afterwards moved it into its place, and supported it in an horizontal situation.

The Mirror of the Forty-feet Telescope

The metal of the great mirror is 49½ inches in diameter, but on the rim is an offset of ¾ inch broad, and 1 inch deep, which reduces the concave face of it to a diameter of 48 inches of polished surface. The thickness, which is equal in every part of it, remains now about 3½ inches; and its weight, when it came from the cast, was 2118 lbs. of which it must have lost a small quantity in polishing. An iron ring, 49½ inches in diameter within, 4 inches broad, and 1½ inches thick, has at the face of it on the inside a strong bead or rim addded to its thickness, which fits the offset in the speculum, but is not quite so deep as that. A cross of the same substance of iron as the ring, goes over its back, and when the speculum is placed into the ring, so as to rest on the offset, the cross over the back confines it in the ring. By the addition of a thin cover of sheet iron on the back, and another of tin on the face, the rim makes a complete case for the mirror. Three strong handles are fixed against the sides of the ring, by which the speculum may be lifted horizontally, or using only one of them, vertically, as occasion may require.

To put the speculum into the tube, there is provided a small narrow carriage, going on 2 rollers. It has upright sides, between which the speculum, when suspended vertically by a crane in the laboratory, is made to pass in at one end, and being let down, is bolted in. The carriage is then drawn out, rolling on planks, till it comes near the back of the telescope. The tube must be put back as far as the bar-machine will permit it to go. Two beams connected together so as to form a parallelogram of 8 feet 6 inches long, and 2 feet broad, are sloped away on one end, while the other contains 2 hooks, by which it may be hooked into 2 holes at the end of the foundation timber, in the middle between the rolling beams. This affords a passage of an easy ascent to the speculum carriage, which must now be brought into a proper position for rolling up. When this is done, the carriage is to be tied to the axle of the point of support, and by turning the bar-machine handle, the speculum with its carriage will be drawn up to the foundation beams, which are 16 inches above the foundation wall. By the time that the carriage comes near the top, there will be

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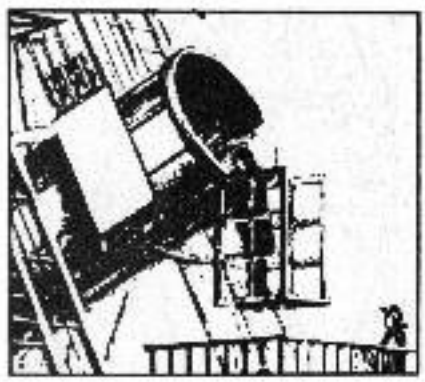
room for 6 3-inch planks that are provided, to be laid one after another on the rolling beams, which will form a platform of 5 feet 10 inches by 5 feet 5, for the reception of the carriage. But these planks must not be put down till the telescope has been first brought back, and fixed again close to the carriage, which must be sustained in its place while this is doing. Then, advancing again, the platform is laid down, board by board, till completed, while at the same time the carriage will be drawn upon it.

As soon as that is safely landed, a strong rope is to be hooked into a loop, fixed on the beam. This going down to a pulley with a swivel hook at the bottom, which is put through one of the 3 handles of the speculum, returns to a pulley hung on the hook. From that pulley it goes forward to a leading pulley on the foundation timber. This directs the ends of the rope to the barrel, which serves for the great round motion of the whole telescope. When the handle of that machine is moved, the speculum will be lifted up in its carriage, which being eased, must now be turned about while the mirror is yet partly resting on it, so as to become parallel with the back of the tube, and close to it. As soon as the mirror is fairly suspended, the carriage must be unbolted, and drawn sideways from under it. At the same time the platform must be gradually removed, that the tube may be brought back by the bar-motion, whenever the mirror is high enough to pass over the back of it. Then letting down gently the round motion handle, and guiding the mirror properly, it is to be placed on a small hollow square, with a sloping back, which is planted under its support. The height of the square frame is such as will bring the centre of the mirror into the centre of the tube; and the sloping back receives it in going down, and throws it from the back of the tube, just as much as is required to make the adjustment at the top act properly.

When the mirror is in its place, 2 loops, which are prepared, are to be screwed fast to it. They contain the collets that receive the adjusting screws from the back, through the strong upper bar, and as soon as these are fastened the pulleys may be unhooked, and all the apparatus that has been used removed. The 6 planks are then to be raised on the same rolling bars, where a passage across the work is wanted, and where they may remain till zenith sweeps require them to be moved.

The method of preserving the speculum from damp is by having a flat cover of tin soldered on a rim of iron, about 1¾ inches broad, and ⅛ inch thick, the diameter of which is equal to the iron ring which holds the speculum. On the flat part of the rim is cemented, all around, some close-grained cloth of an equal breadth with the rim. The cover has 2 handles near the upper end, and under them 2 flaps that project about an inch and are 6 inches broad. When the cover is hung or laid on the speculum, so that the 2 flaps are close to the ring which incloses it, the rim of the cover, as far as it is lined with cloth, will rest against the edge of the iron ring, and fit it all around very closely.

To take off and put on again the cover, a small ladder is provided, which being set at the outside against the back of the tube, the person who is to uncover it goes up, and descends into the tube by means of a board with steps. This board goes across the mirror in a parallel direction with it, and being narrow, does not interfere with the work of loosening the screws to take them off. When they are removed, the person comes out of the tube the same way, still leaving the speculum covered, but when at the top of the ladder brings out the inside board-steps. The 2 handles of the cover now present themselves



at the back, so that 2 persons can easily lift it off, without suffering it to touch the mirror in any place. It must then immediately be carried into the observatory, and remain there till the mirror is to be covered again; but first of all the inner and outer cover of the tube ought to be carefully closed up. When the speculum is to be covered again, great care is required to see that no drops of dew may fall from the outer cover of the tube on the inner one; or at least that these may not find their way to the mirror; and to let the first object be to put its own cover on it before any thing be done about fixing it there.

A slider, on an adjustable foundation, is planted at the mouth of the telescope, so as to be directed towards the centre of the mirror. It carries a brass tube, into which all the single eye-glasses, or micrometers, are made to slide. When they are nearly brought to the focus, a milled head under the end of the tube turns a bar, the motion of which adjusts them completely. The focus of the great mirror is directed to its proper place, by putting 2 plates with springs on the rim that limits the aperture of the tube, into 2 places which are marked. Then a cap with a small hole being put into the sliding tube, an assistant with a proper handle must screw in or out one or other of the adjusting screws at the back of the mirror, till the plates on the aperture in front of the telescope become both visible; for they are contrived so that when the mirror is not properly adjusted, either one or both will vanish. At the same time these plates, by their situation, serve to inform us which of the screws, whether that to the right or that to the left, is in fault, by which means the adjustment becomes a very easy operation.

Moving and Aiming the Forty-feet Telescope

The telescope may be set to any altitude, up to the very zenith. In order to have the direction of it at command, a one-foot diameter quadrant of Mr. Bird's is fixed at the west side of the tube, near the end of it, inclosed in an iron case; on the top of which is also planted a finder, or night-glass, about 21 inches long, with cross wires in the focus. The divisions of the quadrant are indicated by a spirit-level, instead of a plumb-line.

There are provided two means of moving the telescope in altitude. First is by means of ropes and tackle at the front of the tube. Second, the point of support of the bottom end of the tube is moved forward and backward. A graduated wheel shows how many turns of the handle have been made to move the telescope from its most backward point of support to the most forward. This machine is called the bar-index. It is of eminent use in giving immediately, by means of a table made for that purpose, the place of the point of support for any given altitude or zenith distance of the quadrant.

In order to come at every part of the heavens, the vertical motion of the telescope requires the addition of the horizontal one. This has been obtained by another very simple mechanism that rotates the entire super-structure and the telescope with it. With the assistance of the motions that have now been described, I have in the year 1789, many times taken up Saturn 2 or 3 hours before its meridian passage and kept it in view with the greatest facility till 2 or 3 hours after the passage; a single person being able, very conveniently to continue both the horizontal and vertical motions, at the command of the observer.

In this, however, is included an assisting 3rd motion, which I am in the next place to explain. The ladders are set at 8 feet 2 inches distance in front, to permit the telescope to have a side motion, without displacing the whole apparatus, which is designed for a meridional situation. Every celestial object, when it passes the meridian, is then in its most favorable situation for being viewed, on account of the greater purity of the atmosphere in high altitudes. The advantage also of being able to direct the instrument, by means of the quadrant, to the spot in which we are to view the object, is considerable in so large an instrument as the 40-feet telescope. With unknown objects, it is also of the greatest consequence to be enabled, by a meridional situation, to ascertain their place. But as a single passage through the field of view, especially with examinations of the heavens in zones, would not have been

sufficient to satisfy the curiosity of an observer, when a new object presented itself, it became necessary to contrive a method to lengthen this interval. The tube therefore is made to rest with the point of support in a pivot, which permits it to be turned side-ways. Its diameter being 4 feet 10 inches, and that part which is generally opposite the ladders that confine it in front being about 35 feet from the pivot, it appears that a motion of 3 feet 4 inches may be had, which to the radius of 35 feet gives upwards of 5° of a great circle. Several abatements must be made on account of the disposition of the apparatus that gives this side motion, and the shortness of the ropes in high altitudes; but there remains, notwithstanding, a sufficient quantity of this lateral motion to answer the purpose of viewing, pretty minutely, every object that passes the meridian.

Observing with the Forty-feet Telescope

The method of observing with this telescope is by what I have called the front view; and the size of the instrument being such as would permit its being loaded with a seat, there is a very convenient one fixed to the end of it. The foot-board or floor, is 3 feet broad, and 2 feet 2½ inches deep. The seat is moveable from the height of 1 foot 7 inches to 2 feet 7 inches, not so much for the accommodation of different observers, as for the alteration required at different altitudes, and which amounts to nearly 12 inches. One half of the seat falls down, to open an entrance at the back; and being inclosed at the front and sides, a bar which shuts up the back after the observer is in his place, secures the whole in such a manner as to render it perfectly safe and convenient. There are 2 strong iron quadrants with teeth, at the sides of the seat, in which run 2 pinions fixed on a bar, with a ratchet and handle at the end of it. By turning this handle, the seat is easily brought to an horizontal position, before the observer enters it; or restored to it, when any considerable alteration in the altitude of the telescope renders a change necessary.

The focus of the object mirror, by its proper adjustment, is brought down to about 4 inches from the lower side of the mouth of the tube, and comes forward into the air. By this arrangement, there is room given for that part of the head, which is above the eye, not to interfere much with the rays that go from the object to the mirror; the aperture of the speculum being 4 feet, while the diameter of the tube is 4 feet 10 inches; especially as we suppose a night observer will prefer some kind of warm cap to a hat, the rim of which might obstruct a few of the entering rays.

For keeping an object in view, a long coarse screw-bar is confined in a collet, which takes on and off, and may readily be put to the inclosing right side of the seat, so as to present the observer with a short handle. The other end of this bar passes into a nut, which, like the collet, moves on a double swivel, so as to admit of every motion. The nut is planted on a machine which will be described hereafter, and may be drawn up to any altitude, so as to bring the nut on a level with the swivel of the handle. On turning the handle, the observer will screw himself, the seat, and the telescope, from the ladder; and may thus follow the object he wishes to pursue in its course, for as many minutes as may be convenient. If indeed he is inclined to give up the meridian for some time, he may order the whole frame to be moved by the great round motion, which ought to be in readiness; and may even keep his object in view, as I have often done, by screwing the telescope backwards as fast as the round motion advances it. Then screwing himself forward again, he may repeat these successive motions as long as he pleases.

In those observations, which I have called sweeps, several conveniences are required. The principal of them are as follow: 1) an assistant, provided with an apparatus for writing down observations; with catalogues of stars, atlases, and other resources of that kind; 2) a small apartment, as near to the observer as possible, in which this apparatus, with candles and other conveniences, may be inclosed; 3) a sidereal time-piece; 4) a right ascension apparatus; 5) a polar distance apparatus; 6) a polar distance clock; 7) a zoned catalogue of the stars; and 8) a ready communication between the observer and assistant, both ways. There is also wanting 9) a person to give the required motions for sweeping the zones of the heavens; 10) a micrometer-motion to perform the sweeps; 11) a zone-piece, to point out the required limits of the intended zones; 12) a small apartment to inclose these motions; 13) the candle which is required for the workman; and 14) a ready communication, for the observer to direct the workman in the required motions. The distance between the observatory and the end of the telescope is evidently too far for a conversation in the open air, between the observer and assistant; especially as the latter, on account of his candles, must be inclosed; and ought not to leave his post at the time-piece and writing-desk. Add to this, that when the observer is elevated 30 or 40 feet above the assistant, a moderate breeze will carry away the sound of his voice very forcibly. A speaking-pipe was therefore necessary, to convey the communications of the observer to their destination. At the opening of the telescope, near the place of the eye-glass, is the end of a tin pipe, into which at the time of observation a mouth-piece may be put, which can be adapted, by drawing out, or turning side-ways, so as conveniently to come to the mouth of the observer, while his eye is at the glass. This pipe is 1½ inches in diameter, and runs down to the bottom of the telescope, to which it is held by proper hooks, that go into the tube, and are screwed fast at the inside. When it is arrived as near to the axle as convenient, it goes into a turning joint; thence into a drawing tube, and out of this into another turning joint; from which it proceeds by a set of sliding tubes towards the front of the foundation timber.

The micrometer-motion required for sweeping the heavens, and indeed for viewing the planets or other objects, is obtained by means of the end of the rope which draws up the telescope. This goes down to a barrel 12 inches long, and 4 in diameter, joined on the same axle with another barrel, 12 inches long, and 12 in diameter. A smaller rope goes from the largest barrel into the working-room, where it is fastened to the top of a thin vertical spindle, 2 feet 6 inches long, and 3 inches in diameter. Another rope of equal size is fastened to the bottom of the same spindle; and when by turning the handle, the former rope is wound on the spindle one way, this rope is wound off the contrary way. This 2nd rope goes out of the work-room over a pulley, which leads it upwards to the top of the middle cross beam of the ladders, where it descends over another pulley, by a weight with shifters which is suspended to the end of it. In this manner a balance is obtained between the stress of the ropes, which leaves the spindle at rest in any position where it may chance to stand, and considerably eases the labour of the workman, who turns this handle a certain number of times one way, and then the same number of times back again. By such a motion of the handle the telescope is alternately depressed and elevated; and this being continued for as long a time as the observer chooses, enables him to review the heavens as they pass by the telescope.

By the arrangement of the barrels, it is easy to see that the motion is sufficiently divided; as many turns of the handle are wanted to pass over a small space of the heavens. The method of barrels and ropes is to be preferred to wheel-work, on account of the smoothness as well as silence of the motion, both which in observations of this kind are highly necessary. It is true that the great stress which lies on the ropes of the micrometer-motions wears them out very fast, and they must therefore be carefully watched, and often renewed; but this ought to be no objection where the end to be obtained is of such consequence.

William Herschel
Slough, England

Herschel's forty-foot telescope is sometimes described as unproductive, unwieldy, an expensive boondogle. But was it really that bad? Herschel built the instrument for its light gathering power, and was certainly aware that the Herschelian (off-axis) optical system would give poor resolution. Faced with the low reflectance of speculum metal Newtonian diagonal, however, he was willing to make that sacrifice. Perhaps, however, the difficulties in operating an instrument so large did surprise him. Herschel's comment on the matter: "A forty-foot telescope should be used only for examining objects that other instruments will not reach. To look through one larger than required is loss of time, which on a fine night, an astronomer has not to spare."

—R.L.B.

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how to make a lens

Lens grinding is fun: things happen quickly and that's what I like best. Unfortunately, there seems to be some kind of "bugaboo" attached to lens grinding — perhaps it seems too complicated or amateurs have heard exaggerated stories of some kind. But most of it is just lack of familiarity. There is today an extensive array of literature for those interested in mirror making. Any reasonably handy person can follow Thompsons's **Making Your Own Telescope** (or any one of several other books) to complete a good reflecting telescope. If, however, you're looking for help on lens making, you're in trouble. Very little help exists.

This article, then, is intended to present the essentials of lens making to amateur telescope makers. We'll assume you've ground a mirror or two and you're looking for a project perhaps a bit more sophisticated than just another bigger Newtonian.

The equipment needed for making lenses will last you a lifetime. If you belong to a club, the group might want to pool their resources and share the equipment — thus making lens grinding available to everybody. We'll start, therefore, with a description of the various pieces of equipment you'll need and how to go about building them.

A Lens Grinding Machine

Your machine should be compact, use commercially available parts where possible, and provide a variety of running speeds. The device basically consists of a rotating vertical shaft that holds the lens, a tray and shield to keep abrasives from spattering all over the room, a motor and pulleys to drive it all, and a bench, in my case a modified Sears workbench, to support the other parts.

Depending on whether machine shop facilities are available to you, the design of the machine can be very simple (such as pillow block bearings and standard line shafting) or a more sophisticated design such as the one described here. Don't feel obliged to build a fancy machine — even the simplest machine can turn out good lenses.

Substantial machining is required on the spindle and bearing assembly on the particular machine shown in the photograph. Because machining costs are high, it could cost you several hundred dollars to farm this work out. Write this author for detailed drawings of the spindle if you do your own machine work at home or have a friend who'll do it for you.

Whatever plans you adopt, you must provide a way to mount grinding tools — either a flat surface for glass tools or a standard tapered shaft (available from Universal Shellac)which can be screwed onto it for use with standard commercially available iron tools. For bearings, use Fafnir 203K or equivalent, available at any bearing supply house.

If machining is very difficult or impossible for you, however, make the spindle assembly from low-cost pillow-block bearings, restraining collars, standard pulleys, and other parts available in large hardware stores, notably Sears in the U.S. and Canadian Tire in Canada. The only machining then

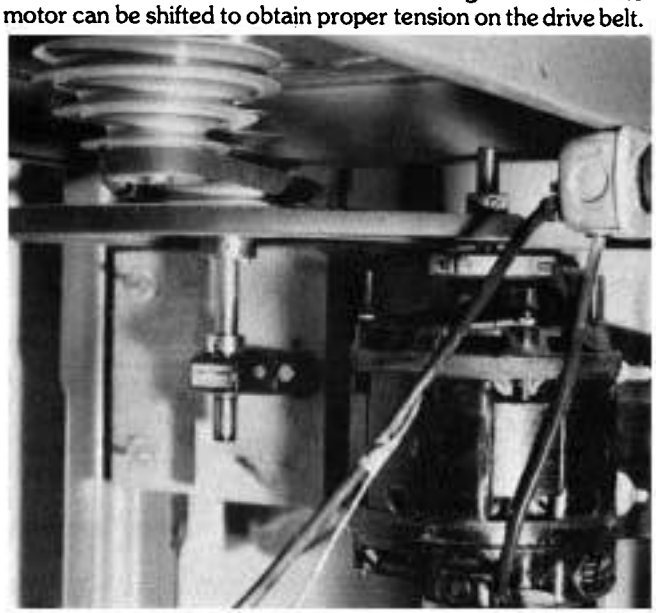
New possibilites open for the telescope maker who can make his own lenses -- compact, high-performance optical systems that avoid the difficulties of a paraboloidal primary.

required is for a grinding tool adaptor you can press-fit or slip over the rotating shaft. To make an abrasive trap, fit a rubber collar about three inches in diameter over the top of the adaptor. Extending above the top of the central pan opening and rotating with the shaft, it will spin off any abrasives that fall on it. Pillow block bearings will wear out faster than ball bearings, but their life will be several years in any case.

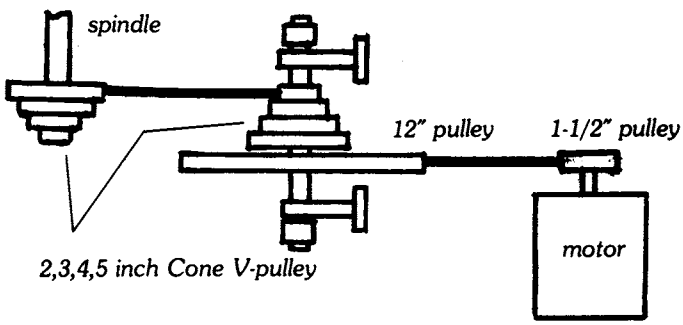
The motor is a 110-volt, quarter-horsepower motor. I got mine from a junked washer. It happens to be a 2-speed type that is used on Kenmore, Speed Queen, and many other brands. The shaft speeds are 1140 and 1725 r.p.m. A single-pole double-throw center-off switch changes motor speed. A foot switch should be wired in series with this switch. Get into the habit of turning the center-off switch to the off position whenever you're changing belt positions, etc., so that if the foot switch is inadvertantly depressed, the motor won't come on and injure you. Be sure to ground the motor properly.

There is no way to give the spacing from the motor to the intermediate shaft or from there to the spindle, because there is a rather large length tolerance on any given belt size. Nor is high belt tension necessary because the loads are very small for V-belts. Since the top of the bench is held in place by wood screws on my machine, I can reposition the top to get the proper belt tension connecting the step pulleys. The belt must be shifted to different grooves to obtain different r.p.m.s.

The motor mount holes should be elongated so that the motor can be shifted to obtain proper tension on the drive belt.

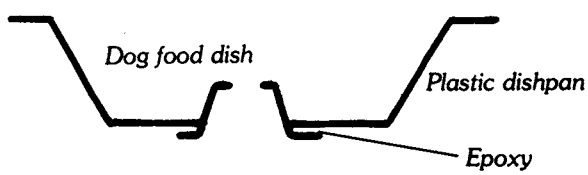


My grinding machine is a converted Sears workbench. I bolted a 2 x 8 between the legs at the right hand side to support the motor and a 2 x 4 to which the pillow blocks are attached.



With the pulley arrangements shown here, and by combining the use of the 2, 3, 4, and 5-inch step pulleys and the two speed motor, I obtain spindle speeds of approximately 50, 85, 100, 160, 190, 290, 350, and 540 r.p.m.

Make the splash pan from plastic or something soft. It will catch grit as well as the occasional flying lens that slips from the worker's grasp. A plastic washpan and an inverted doggie-bowl joined by silicon plastic caulking compound (as shown in the cutaway diagram) is an inexpensive and practical arrangement. If a hard pan must be used, line it with something soft like foam plastic, cork, or felt; then cover that with thin plastic to avoid contamination with grit. To keep abrasive from getting down



into the machine, force a thin round sheet of neoprene rubber with an undersize hole at its center over the shaft so that it runs close to the inverted doggie-bowl. Centrifugal force will fling any abrasives or sludge landing in that area away to the sides of the splash pan.

A Fringe-Testing Rig

To test convex surfaces, you'll interference-test against a concave proof plate. For this type of testing, you need to build a monochromatic light box that will illuminate the pair of glass disks and allow you to view them from straight above.

The tester consists of a G.E. #F8T5/BL "blacklight" lamp mounted in a standard fluorescent light fixture. (Be sure that you don't get a bulb with the suffix "BLB" — these are coated to exclude visible light and won't work.) This bulb emits the green line of mercury at 5461 Angstroms, one of the standard test wavelengths in optics, as well as several other lines. To isolate the 5461 line, mount a sheet of 1/16" thick #2092 green plexiglas

►

how to make a lens

below the bulb, with a sheet of tracing paper on top of the plexiglas to act as a diffuser.

A standard fixture won't fit across the box with the dimensions given, but it can be mounted at an angle so that it will fit, or you can alter the dimensions of the box.

The sheet of ⅛" window glass on the 45° angle acts as a beamsplitter. It allows you to see the interference fringes properly because you can view them perpendicular to the lens surfaces by the partial reflection in the glass. The box itself can be made from plywood, masonite, hardboard, or any other handy material. Cover the bottom and back side of the box with a piece of black velvet or other black background material.

The operation of the interference tester will be described later, when we come to actually use it.

The Wedge Jig

You'll also need a jig to measure the "wedge" in lenses. "Wedge" means that one side of the lens is thicker than the other, so the lens has a prismatic effect. One of your goals in lens making is to keep the amount of wedging small.

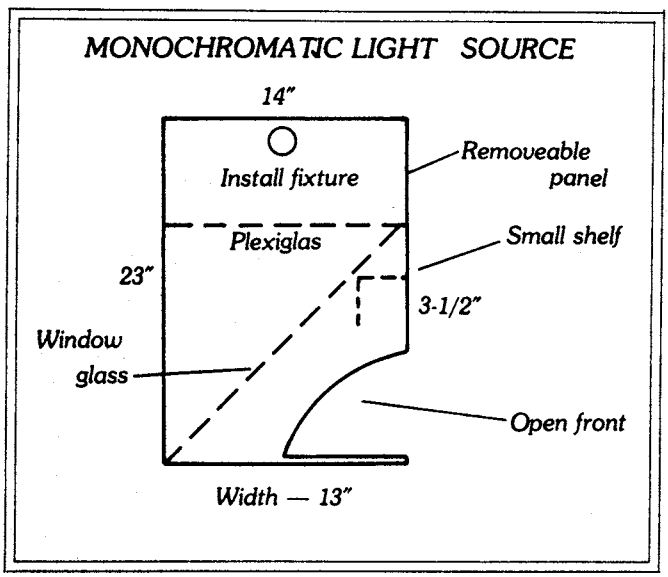
Three ball surfaces are set on a base to support and define the plane of the lens to be tested. Two vertical posts locate the test lens laterally. They allow you to rotate the lens and still keep it in the defined plane. An indicator touched against the top side of the lens lets you measure its thickness at that spot; you then rotate the lens and measure several places around its circumference. Differences in the readings indicate the amount of wedge.

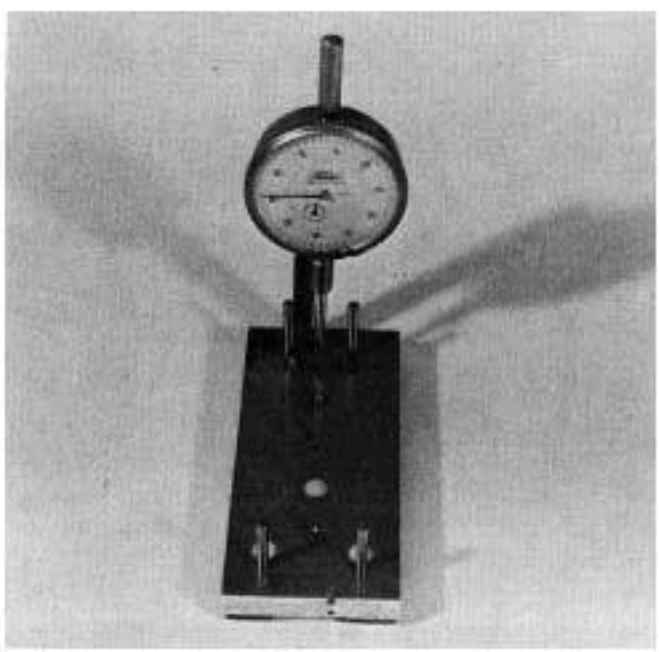
The best indicator is a dial-type reading to 0.0001" (1/10,000 inch), however it's possible to use a less expensive 0.001" dial indicator and estimate fractional parts between its divisions to about 0.0002" on a consistent basis. If cost is an important factor, then a micrometer spindle can be substituted. With a ball surface on the measuring face, reasonably consistent results can be obtained. It may take some practice, however, to get the feel of "just" contacting the lens surface in the same way with each reading.

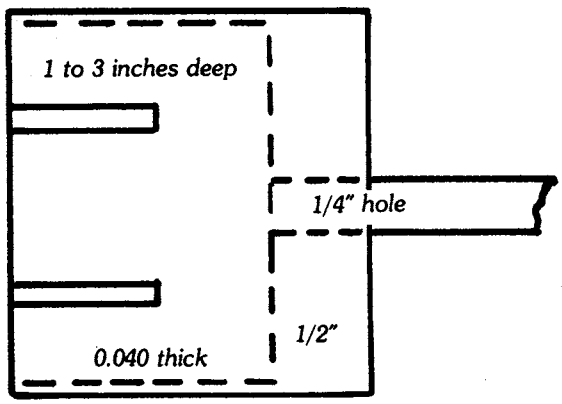
The Knife-Edge Tester

A knife-edge tester capable of making measurements accurate to 0.001" is necessary. For stability, it's a good idea to mount the tester and the holder which supports the lens on the same base. For best results, the tester should be somewhat more solid than typical homemade Foucault testers so that once you've calibrated it, every little knock won't mean a recalibration.

For measuring the longitudinal travel, a 1" travel dial indicator reading to 0.0005" measures the travel of the knife-edge. You can use the same one that you'd use on the wedge-







BISCUIT CUTTER

measuring jig or on a spherometer you'd use for mirror grinding.

The unit is zeroed by inserting a machined brass rod (with smoothly rounded ends) of known length between the test surface and the vicinity of the knife-edge. Gently bring the knife-edge up to touch one end while the other end touches the lens. The dial is then set. For example, let's say the lens under test should have a radius of 3.141". The rod should have a length near that: say it comes out to 3.136". You would then set the dial to read 0.136" plus one-half the thickness of the knife-edge. The dial now reads the actual radius directly; if you tested the lens and got a 0.333" reading, the radius of curvature of that surface would be 3.333".

Measuring Tools

You should have a micrometer precise to 0.001" and a vernier caliper with a range of 6 inches or more. Buy the best you can afford. When purchasing a vernier caliper, the ones with a setscrew are preferable to those with a thumblock. Buy ball attachments for the micrometer to be used for measuring edge and center thicknesses.

Grinding Tools

When discussing the grinding machine, we mentioned that standard optical grinding laps can be purchased. The tools are made of fine-grain cast iron, and are made in standard curves as well as flat. The chances of buying one having just the right curve for your lens are small, and custom curves cost extra. Also, in order to keep their surfaces true, you have to buy them in pairs (concave and convex) and grind them against each other once in a while. After you've ground the curve into the glass, you'll often find that it's not exactly the right radius. Then you'll have to make a glass tool (by grinding against a metal tool) to finish the workpiece to the proper radius.

This all means that metal tools can result in a lot of trouble and extra work. I now use only glass tools; after trying both methods, I'm convinced it's easier for an amateur. In this article we'll only discuss the use of glass tools. If, however, a club project involves lens grinding and many workers will be grinding the same curves in glass, then it's easier and more practical to go to metal laps.

Biscuit Cutters

You'll need biscuit cutters for making lens blanks and tools to size for grinding. As a general rule, these cutters are machined from aluminum or brass on a lathe. Make the I.D. about 0.025 inch larger than the diameter you want in the glass blank because some glass will be lost in the cutting process.

The cutter wall thickness should be between 0.030 and 0.040 inches, with six to eight vertical slits cut in the wall to allow abrasive and lubricant (usually water) to flow. If you hacksaw the slits, do it before turning the walls to the final dimensions to avoid buckling.

If the right size can be found, some workers use an old tin can as a cutter, with a bolt, and if necessary a wooden stiffening disk, fastened to the bottom. Tubing of the proper wall thickness can also be used.

The use of biscuit cutters is discussed later in this article.

Supplies

You'll need the following optical supplies. They can be purchased from the Electro-Optics Division, Universal Shellac and Supply Company, 495 West John Street, Hicksville, NY 11801.

1.) 2 to 5 pounds of 142μm Unasil (silicon carbide);
2.) 1 pound of 66μm Unasil;
3.) 1 pound of 30μm Microgrit;
4.) 1 pound each of 25μm, 12μm, and 9μm Microgrit;
5.) 1 Unipak (9½ pounds) of #450 semi-hard polishing pitch;
6.) 5 sticks of #9 centering wax;
7.) 1 pound optical quality resin for pitch hardening; and
8.) 1 small bottle of turpentine to soften pitch, or a small amount (about 3% by weight) of pure beeswax will serve the same purpose.

Other materials that you will need can be obtained locally. These are:

1.) Modeling clay for use in biscuit cutting;
2.) A rubber syringe for blowing dust off surfaces to be interference-tested;
3.) Windex glass cleaner for cleaning glass before testing;
4.) Nylon net (from a fabric shop) for use in lap-making;
5.) A propane torch for melting wax;
6.) Plenty of scrap plate glass for making templates; and
7.) A glass cutter, carborundum stone, etc., etc., which you are likely to have if you're already a mirror-maker.

Shop Support

You may have noticed that a lathe and drill press would be handy to have for making lenses. While this is certainly true, you can do pretty well if a friend or school will let you use theirs from time to time. A well-equipped home workshop is essential.

Getting Ready to Make a Lens

We've now described nearly everything you'll need to make a lens. However, to make a particular lens needed for a specific optical system, you'll need one or more templates to gauge your progress in obtaining the correct radii on the surfaces.

You can purchase very accurate templates in standard diopter sizes from Universal Shellac. Each has a concave and a convex curve (on opposite surfaces) and they sell for less than $3.00. Brass gauges cut to order are less than $10.00 a pair, or about $6.00 for a single radius. But it's nice if you can manufacture accurate templates yourself.

Small radius templates can be cut from a disk machined on a lathe. However, most radii you'll need are in the neighborhood of 10" to 12". These would require machining disks 20" to 24" in diameter — not practical unless you have access to the lathe at your corner railroad overhaul shop!

It's possible to get away with a paper template made with a knife, a nail, and a wooden stick. This works as follows:

Cut a piece of pine ⅛" thick by about ¾" wide, and an inch longer than the radius you want. Drill a hole 1/16" diameter about ½" from one end, and mark the radius distance at the other end. Drive a nail through the stick at the mark and into the top of an old, but not antique, table or workbench top. Tape a piece of card stock to the table top under the drilled hole. Into the 1/16" hole, insert the point of a #11 X-acto knife blade. Cut the card with one steady motion. Since accurate testing of the radius must be done optically anyhow, the paper template will serve to get you into the right ballpark. Optical testing begins early, so no problems should arise. ➤

how to make a lens

Glass templates are better than paper and can be made with a glass cutter. The Sears carbide wheel model is a good one. Attach the cutter to the end of a piece of wood ½" or ¾" square and somewhat longer than the radius you wish to cut. If you're making several templates at once, make it long enough to handle all of them.

Drill a small hole in the wood so that the cutter point will scribe the correct radius when the beam is swung around that point. Tape a piece of single-strength window glass to your benchtop. Drive a finishing nail or steel pin into the benchtop so the cutter will swing across the glass, moisten the glass with turpentine (this helps the glass to cut smoothly), then, bearing down with moderate pressure, scribe the arc on the glass. Make one pass, and one pass only, otherwise the glass may not break cleanly along the cut. Quickly untape the glass, place a finishing nail under the scribed arc, and press down on each side of the glass. It should break cleanly along the cut.

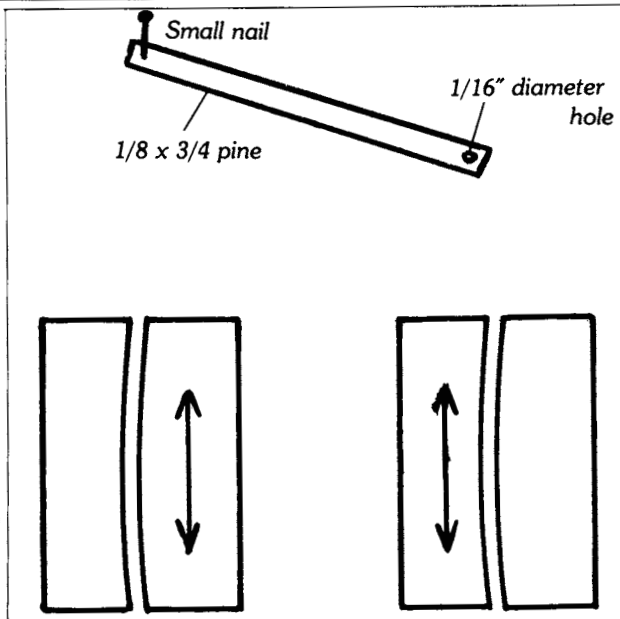
The cut edge will require smoothing. Place the pieces of glass on the benchtop again, and put some 30μm abrasive and water on the edges you've cut. Work the pieces back and forth with a ¼ or 1/3 stroke moving first one piece and then the other. Don't work them too long or the curve may alter — just enough to smooth the edge. One side of each (not the edge) can be spray painted with black laquer to make it easier to see departures from the curve between the lens and the template.

Making a Lens: Rough Shaping

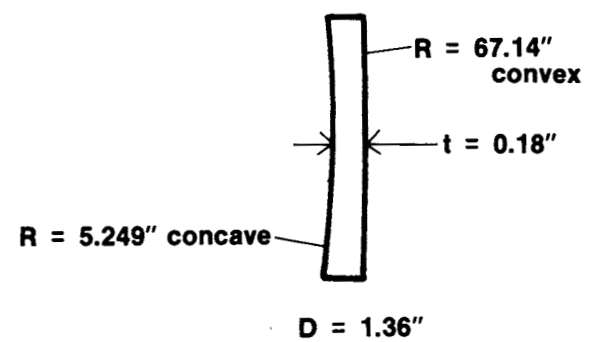
To convey the process of lens-making, let's go through all the steps with an example. We'll discuss grinding a meniscus lens (so we'll have concave and convex surfaces), with a diameter similar to what might be required for a relay telescope or a Jones-Bird catadioptric Newtonian with about a six-inch aperture. We'll make one of the radii long, and the other short. Here, then, are the specifications:

Diameter	1.36"
Clear aperture	1.27"
Radius of concave face	5.249"
Radius of convex face	67.14" ± 0.067"
Central thickness	0.180"
Glass type	BK-7 or BSC-2

To make this lens, you'll need a blank and four plate-glass tools, plus a plate-glass proof plate and tool for the concave surface. Furthermore, you'll need four templates in two pairs, a concave and a convex of each radius. Tools for small lenses can be made from ¼" plate glass, and for larger lenses, use ⅜" plate. They should be 1.2 times the diameter of the lens (this isn't too



GRINDING TEMPLATE EDGES



A MENISCUS LENS FOR PRACTICE

fussy though) or a minimum of ¼" larger than the lens. The proof plates should also be somewhat larger than the surface to be tested.

More than likely, the optical glass you'll use will be in the cheapest form, rough square blanks from which disks must be cut. The plate-glass for the tools will certainly be cut from sheets. You'll be using a "biscuit cutter" (described earlier) to cut the blanks out.

For our example, the lens itself should be cut with a biscuit cutter about 1.385" I.D., or about 0.025" over the desired lens diameter. The proof plate should finish out at about 1.400" diameter, and the tools about 1.625" diameter.

To biscuit-cut, clamp the glass to the table of a drill press, using several paper towels under and around the glass to cushion it and help keep it from moving. (You can also use the fence to keep the glass from spinning — but whatever you do, make sure it's firmly anchored.) Mold a circular dam of modeling clay about ¾" to 1" larger than the diameter you intend to cut. Add about ⅛" of water and a tablespoon full of 142μm carbo. The drill press should run between 200 and 300 r.p.m. if possible. Bring the cutter down to the glass and apply enough pressure to make a squealing sound. A wooden "sucker stick" will help distribute the water/abrasive mixture, as will occasionally pulling back out of the cut. Try to insure that there is always abrasive between the cutter and the glass — remember that it's the abrasive that's doing the work!

Slow the cutting when coming through the rear of the glass to minimize chipping of the edges. In the event that chipping does occur, the chipped surface can be used as the convex surface of the lens, since small chips on that side will automatically be ground away. You can also wax the glass to a sheet of ⅛" or thicker window-glass to minimize chipping.

To prevent scratches and edge chips, bevel all edges with a medium carborundum stone. Be sure, at all stages in the work, to keep a bevel 1/32" to 1/16" wide on all lenses and tools.

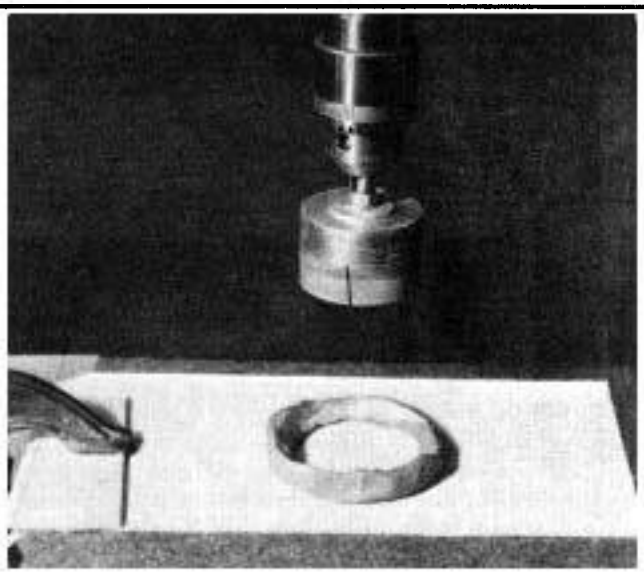
Grinding

Grinding involves two basic strokes, one which lengthens the radius and one which shortens it. A stroke somewhere between the two will maintain a constant radius. The glass tool is always used on the bottom.

As shown in the accompanying drawings, if the lens is worked on the tool so that its outside edge never goes more than 1/32" beyond the edge of the tool, then a convex curve will lengthen and a concave one will shorten. If the lens is carried over the edge of the tool by about 1/3 its diameter, then you will cause a convex curve to shorten and concave to lengthen.

The 1/32" overhang is done to prevent a raised lip from forming on the tool, but this overhang should be kept as small as possible.

In fabricating the lens in the example, our first step is to complete a proof plate for the convex face. Attach one plate-glass blank 1.625" diameter (the tool for the proof plate) to the spindle of the grinder with double sided tape. Center it as accurately as you can. (Be sure that the edges are beveled.) Set the spindle to run at about 85 r.p.m.



SETUP FOR BISCUIT CUTTING

Begin by placing about ¼ teaspoon of 142μm grit on the tool and adding a few drops of water. Take another tool blank and set it on top of the first disk. For good control, grip it between the thumb and index finger of both hands. Apply pressure at the center of the disk with the first fingers. Start the spindle rotation with the footswitch and use a 1/3 diameter center-over-center stroke of the top disk over the bottom one. Ease the finger pressure on the top disk to allow it to rotate with motion picked up from the bottom disk. Don't be too upset if the top disk goes flying across the pan if you apply a bit too much pressure or the abrasive slurry becomes too dry: even the most experienced workers get a "flying lens" now and then.

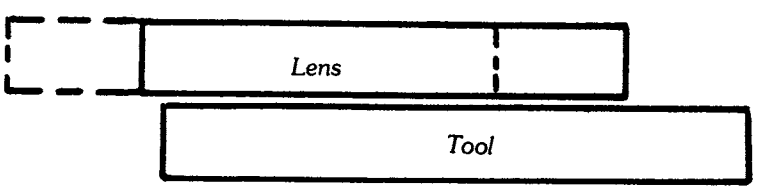
Repeat with two or three wets, then check the lower disk with the template to see if the convex curve has reached the right radius. Keep checking from time to time; when it does, your tool is ready. (Remember to keep the edges properly beveled; once on the spindle, you can hold the carbo stone against the rotating disk and bevel very quickly.)

You have just "preshaped" the tool. Though it may seem a strange way to do things to a mirror maker, as a lens-maker you'll find it saves time and aggravation in the long run.

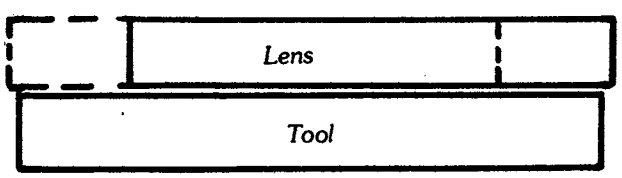
Protect the better side of the proof plate with tape — you'll want to look through this surface later on. This tape will need to be replaced frequently.

The concave proof plate blank can now be ground on the preshaped tool. Since the curve has a very long radius (67.14"), very little glass will have to be removed, so grinding can start with 30μm grit. Try to grind in a manner that will wear the tool as evenly as possible; this is best accomplished by working the center, near edge, and middle of the tool with a one-third diameter stroke with the blank. ➤

GRINDING AND POLISHING STROKES

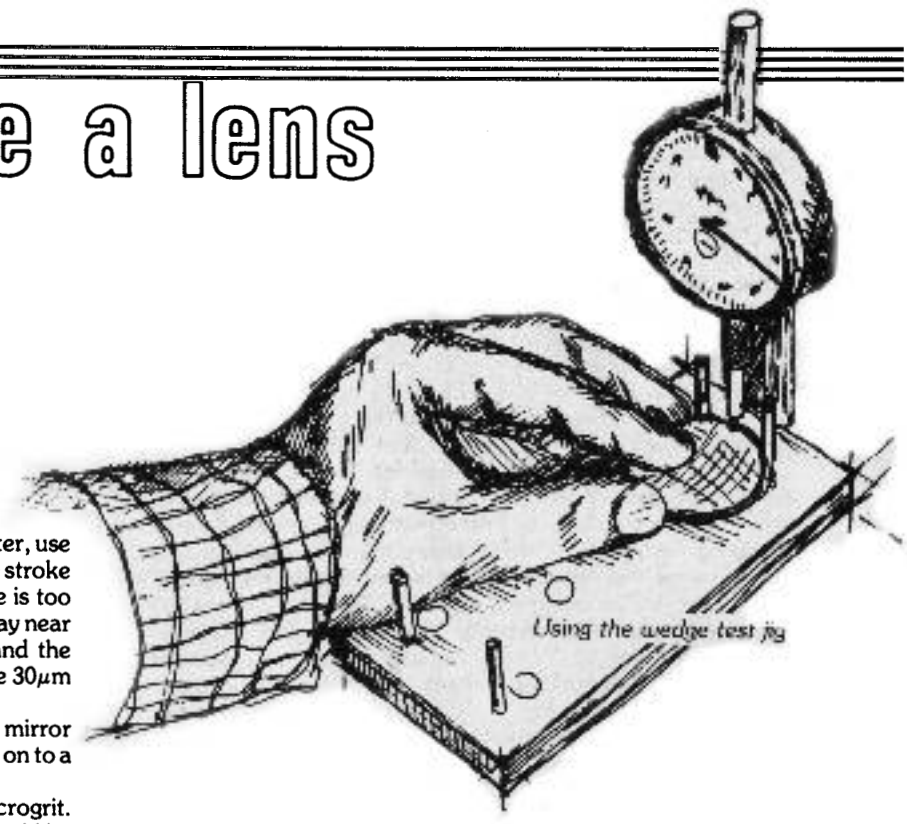


To lengthen convex and shorten concave lens surfaces



To shorten convex and lengthen concave lens surfaces

how to make a lens


Using the wedge test jig

When the curve covers about half the blank diameter, use the template to check the curve. If necessary, adjust the stroke you are using to make the two curves fit. If the surface is too long in radius, grind near the edge of the tool; if short, stay near the center. When the curve matches and template and the surface is ground clear across, you are finished with the 30μm grit.

Cleanliness is as important in lens-working as in mirror making, so clean up everything thoroughly before going on to a finer grit.

After cleaning up, give the lens 4 wets of 25μm microgrit. Clean up everything again. At this stage, your blank should be smooth and fit its template perfectly. Now a more accurate means of measuring the radius is needed: the knife-edge tester. In order to shine the glass enough to catch a reflection, you'll now "dummy polish" it.

First, the glass is ground with one wet of #9 Microgrit (a 9μm abrasive). This "knocks off the high spots" and aids our quick polish. Next, grind another tool and disk to the correct radius the way you ground the piece ready for dummy polishing — the convex glass of this pair is the glass you'll cast your lap on. Once again, keep edges beveled and after each abrasive, clean up thoroughly.

Use a clean ice-pick or screwdriver to break some of your pitch out of its container. Melt the pitch in a tin can on a hot plate — use a low heat and provide good ventilation for the fumes. Always remember the fumes from hot pitch are flammable.

Wrap the edge of the glass that's going to become the pitch lap with masking tape. Heat it and the piece to be polished in hot water, then pour the pitch to a thickness of 3/32" to ⅛" on the tool. When the pitch cools, remove the tape.

It's obvious that since the pitch lap is larger than the glass we're going to polish, the mirror maker's method of hot and cold pressing aren't going to work. The cross-hatched method of channeling won't work either. Heat the lap and blank in fairly hot water, then press the blank into the pitch. At the same time, work it around with a circular motion so that it comes into contact with all areas of the pitch. You'll probably have to heat the lap and glass several times to get this done. When the pitch is the right shape, some will have oozed over the edge of the glass. Trim this back with a sharp knife or razor blade, beveling the pitch inward a little.

Cut a 3" square of nylon net and rub both sides of it with soap. Warm the pitch and blank. Lay the net on the pitch and press the glass blank against the lap using a circular motion for shaping until the net sinks into the pitch. This process seems rather awkward at first, but stick with it and after a while it'll seem easy.

Make a fairly thick (like coffee cream) mixture of the polishing agent and store it in a small plastic squeeze bottle. Barnesite (or one of the new substitute polishing agents) is best.

Mount the lap on the spindle, carefully centering it on the axis of rotation. Leave the speed where you had it — at 85 r.p.m. Warm the blank slightly. Put a few drops of polishing agent on the surface of the lap, spreading it around with the tip of your finger to cover the surface. Set the blank in place, holding it with both hands, and start the spindle. Here's where the footswitch is indispensible!

The glass will grab and stick to the lap quite suddenly, but hang onto it if you can and try to keep up a stroke that carries the glass ¼" over the edge of the lap. If, after a few minutes of running, the glass is still grabbing and not working into contact with the lap, repeat the pressing by heating the glass slightly and running it against the lap. Always use the circular motion when pressing; if you don't, the lap will end up with a raised rim. Once the grabbing is over, the spindle can be sped up to 400 or 500 r.p.m.

Polish until the glass will reflect light over all, or most of, its surface. Polishing should always either start all over the blank or slightly favoring the center. If the edge starts first, press the lap to correct the contact.

When smooth contact is obtained, speed up the spindle to 400 to 500 r.p.m and polish until the glass will reflect light all over the surface, or from most of its area. Now mount the blank in the radius tester and determine the radius. Don't worry about the figure at this stage, just the center radius.

You'll probably need to go back to grinding using the stroke needed to move the radius in the correct direction. Do 3 or 4 wets then repeat the dummy polish and check the radius again. An appropriate question now would be, "How close do I have to be to the correct radius when I am finished grinding?" Well, a 60" curve can be changed 1" or more in polishing without excessive trouble, a 20" radius will alter by 0.030", and a 6" radius by 0.007". Our radius is 67.14", so we need to be within 1" of this figure when polishing starts.

Go through grinding with the rest of the grits, working carefully to stay within the radius tolerance. You'll need to do 6 wets of each abrasive. Dummy polish every 3rd or 4th wet. After the dummy polish test on the 9μm grit, the surface is

ready for final polishing.

Even though the final polish of the proof plate need not be complete (just enough to easily see interference fringes through), its figure must be a smooth, regular sphere in the Foucault test. If you use the Ronchi test, the bands should appear straight when 3 to 4 show on the surface. Poor surface smoothness is not easy to see with the Ronchi test, however, so perform a Foucault test for smoothness. With an oversize proof plate, some turned edge is allowable as long as it's outside the working aperture of the lens you'll be testing with it. The final radius of the proof plate for our example should be 67.14" ± 0.067".

Most polishing can be done at 400 to 500 r.p.m., but correcting a figure is better handled at slower speeds — 150 r.p.m. or less. You can almost use the same correcting strokes as you do on telescope mirrors. Here, no advice will help as much as practical experience. If you've done a mirror, however, don't think you can't figure a lens. You can.

A word about the lap: if it becomes hard due to frequent pressing, make a new lap. Don't fight a bad lap — it'll ruin a good surface figure. It's a good idea to pour a new lap when you're ready to begin final polishing. If the curve is steep, the lap should be poured over the curved grinding tool for uniform thickness.

Now for the Lens...

After the proof plate is finished, you can make your lens (at last!). First the size of the glass blank must be determined. If you can, get a round disk cut by the glass supplier; it's then possible to dispense with the difficult edging process, and it's easier and quicker in the long run. If you must cut the disk from a square blank, cut it oversize: leave an extra 0.025" on the diameter. You will remove this excess in centering and edging later on.

To obtain the required thickness, add about 0.008" per side to the specified thickness of the finished lens. You'll remove about this much in grinding. If the lens has a concave surface or surfaces, then the sagitta of all concave surfaces must be added to the thicknesses specified. Usually a tolerance will be given on thickness, such as ± 0.004". Add this also. Always aim for extra thickness in finishing, this way you'll have a cushion to work with if a scratch develops.

If, by the way, the designer doesn't give you a tolerance in his specifications, use 0.1% of the radius on all surface curves and 0.004" on thickness. The tolerance that we'll adopt on our radius of 5.249" will be ± 0.005".

Now, let's work out an order for a piece of glass for the meniscus lens previously mentioned. Go back and check the specifications carefully.

Now here's what to look for. The 0.090 inch difference between diameter and clear aperture is ample for mounting and we'll plan no edging for this lens. One side is convex, with a shallow curve, the other concave with a moderately steep curve. The thickness is given as 0.180". Add 0.016" (0.008" per side) for grinding and 0.004" for the thickness tolerance. The sagitta, or height, of the curve on the concave surface, calculated for the full diameter, is 0.044". The grand total is 0.244", but to be on the safe side, specify a thickness of 0.250" in your order. If you intend to cut out your own disk from a rough blank, then the size should be a minimum of 1.500" across to allow room for the biscuit cutter to work.

While waiting for the glass from the supplier, take the tool you ground your proof plate on and reshape it to fit a template of the radius for the concave side of the lens, 5.249". Use 142μm grit for reshaping the tool. Since we'll start the grinding on the lens with this grit, it won't be necessary to do any fine grinding on the surface.

When the lens blank arrives, which we'll assume is supplied with a diameter of 1.36", cover one side with tape and bevel the other side about 1/32" wide. The tape permits you to hold the lens better on the rapidly rotating spindle and later will protect a surface already worked.

On the newly shaped tool, grind one side of the blank using 142μm grit until the unground rim around the edge equals ⅛". The lens disk will contact only at the center when you start, so it will flatten the curve on the tool. For the beginner, it might be advisable to recheck the tool radius with its template frequently. If a poor fit is seen, rework the tool with its matching concave surface to true it up, then continue grinding. If the untouched rim of glass is kept uniform, final wedge control will be simplified, so check it frequently with a millimeter rule or one reading in 0.010" increments. Whatever area has a thicker rim should get a short spell of concentrated grinding to center the ground region on the surface. Proceed with grinding as you did in making the proof plate. Keep a close watch on the radius; use the knife-edge test. Remember that it's easier to shorten a concave surface than to lengthen it, so stay near the long side of the tolerance.

After some two-handed practice, the lens is allowed to rotate by extending thumb and withdrawing the index finger. This works for the spindle rotating counterclockwise, as shown here.

Don't polish out the surface when you finish fine grinding, just leave it dummy polished and cover it with tape. I prefer to do all the polishing after both sides have been ground and are ready for polishing. This practice reduces the chances of scratching.

From our original complement of tools, there are still two left unused. These will now be used for making a concave tool for grinding the convex surface of the lens. Mount one glass on the holding plate and with 30μm grit, shape it to fit your templates radius of 67.14" ± 0.067". (With a curve as shallow as this one, it isn't necessary to go to coarse grits in shaping — the 30μm will cut fast enough.) When the template fits the glass, take the convex piece from the bottom and substitute the concave one.

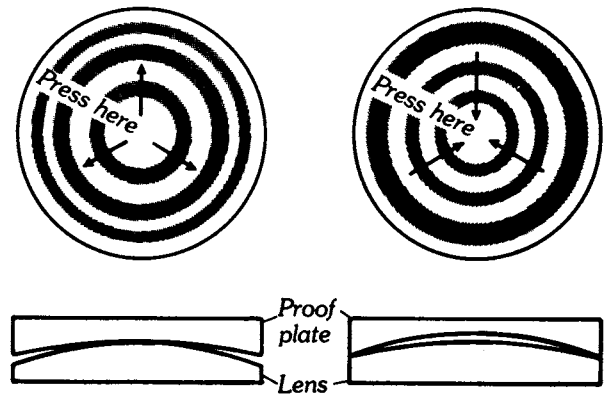
Bevel the lens blank about 1/32" to prevent chipping and begin grinding with 30μm grit. It won't take much grinding to reach a curve depth of only 0.0034"!

When surfacing, use a stroke that carries the lens ⅛" past the rim of the tool. Stop when the flat unground spot in the center is 3/16" in diameter. From here on, in order to control the wedge of the lens, you'll need to use the wedge testing jig described earlier to check the wedge. If the grinding of both

how to make a lens

Rings expand = lens radius short

Rings contract = lens radius long



surfaces has been carefully controlled by keeping the area of unground glass uniform all around the disk, then the wedge will be quite small.

When grinding with 30μm grit, the wedge should be held under 0.0005". If it goes over this, as it more than likely will, grind in the usual manner except apply light pressure to the thick edge for 10 to 15 seconds. Don't try to get all the wedge out at once, you'll just chase yourself all around the perimeter of the blank. Work the wedge down a little more with each change of grit. When grinding is done, it should be 0.0001" or less. If the lens is properly held during surfacing, once the wedge has been removed, the lens will tend to remain exact. But don't rely on it — keep checking just to be sure.

The rough blank as received from the supplier requires the removal of several thousandths of an inch of stock to eliminate saw cut marks or deep pits left from surfacing. Even after the central spot has been removed from the surface, you'll need to remove more stock. Be sure to check carefully with a 10x magnifier that all surface blemishes are gone before proceeding. After 4 or 5 wets, if the original surface was not too rough, change to 25μm grit. After 4 or 5 wets of that, do your first dummy polish so that you can check the radius with the proof plate. You'll have to make up a polishing lap at this point.

Using a Proof Plate

Now comes the most exciting part of lens making, checking the radius of the lens using light waves — it sounds technical and complicated, yet it's simple and easy to do. The procedure is as follows:

Lay a piece of black felt on the small shelf of the light tester. The dark background provides better fringe contrast. Turn on the blacklight lamp. Clean the lens and proof plate with Windex and paper towels. The towel should have little or no lint because any particles on the glass will foul up the test.

Set the lens, face up, on the felt. Use both hands to lower the concave side of the proof plate exactly straight down onto the lens. Do *not* slip or slide the two surfaces together — scratches will surely result. Look at the reflection of the proof plate and lens in the angled sheet of glass and press lightly on the center of the proof plate. You should see a pattern of pale rings, lines, or something in between. This is the interference pattern between the glass surfaces.

If you don't see them, try the following suggestions in the order given:

1.) Turn out all room lights;
2.) Press down on opposite edges of the proof plate;
3.) Reclean both lens and proof plate. Use an ear syringe to blow off dust and lint;
4.) Look very closely at the center. If you see rings there but nowhere else, then the radius of the lens is too short; and
5.) Try more polishing. If you still don't see anything, then the lens surface has a radius that is too long. Shorten it and try again.

Once you do find rings, note that they expand or contract when light finger pressure is applied to the center of the proof plate. The direction of their movement tells you whether your lens is curved too much or not enough. If you see a series of arcs instead of rings, the ring pattern is there, but its center is off the edge of the lens. Pressing will still cause the arcs or bands to move and still tells you the condition of contact between the proof plate and lens.

If central pressure causes the ring pattern to expand toward the lens edge, or the arcs to expand away from the imaginary center, then the lens is too steep, or convex, relative to the proof plate. If the rings contract or the arcs move toward their center location, then the curve is too flat, or concave, relative to the proof plate. In the first case, the lens has to have work concentrated on its center to deepen it; in the latter case, more work should be done at the edge of the lens to make the curve shallower.

The lower the number of rings that show with no pressure applied, the closer the match of lens to proof plate. One or two arcs indicate a closer match while straight bands indicate a perfect match. The usual tolerance for matching radii is two rings showing. Two, or preferably fewer, enable you to decenter the rings and evaluate the surface of the lens for smoothness and regularity of figure.

The actual final match to the test plate depends on the diameter of the lens and the length of the radius of curvature. To determine the maximum number of rings you can have on the test and still be within tolerance on radius (assuming the proof plate is perfect), apply the standard formula for sagitta:

$$S = R - (R^2 - r^2)^{1/2}.$$

Here R is the radius of curvature and r is the radius of the lens surface (half the diameter, or D/2). With your handy pocket calculator, first figure the sagitta for the correct radius of curvature, 67.14 inches, with a lens radius of 0.68 inches, and we find it to be 0.00344364. Do this again but now with the tolerance added to the first radius (0.06714 inches). The new sagitta is 0.00344020 inches, and the difference between that and the correct sagitta is 0.00000344 inches. If you divide this by 0.00001075 inches, half a wavelength of Mercury light, the allowable fringe difference will be found to be 0.320, or about 1/3 fringe or 1/6 wavelength. This means that in the interference test with the proof plate almost straight, line

fringes must be obtained if the tolerance is to be met. Such a close match is unusual and is due, in this case, to the small diameter and long radius for the lens. If, for instance, a test glass had been made for the concave with a radius of 5.249 inches, assuming a tolerance of 0.005 inches, the allowable fringe difference would have been 3.95 fringes. For all practical purposes, you could round that off to 4.

How close must the radius be at the end of the grinding? On a long radius, such as 60", 50 rings or less is close enough. About 10 rings is all right on a radius of 20", and for short radii, 6" or less, 3 rings should be a maximum at the end of fine grinding. Remember, convex curves can be lengthened much more easily than they can be shortened, so stay short if possible.

To be sure of a uniform surface, take at least 0.004" of stock off the lens surface with 30μm grit, then proceed with 6 wets of each grit, checking the radius with the interference tester every 3rd or 4th wet. This long radius is "rubbery" and changes rapidly.

When grinding is done, pour a new lap. Polish until the pits are gone, remembering to check the figure frequently enough that at the end of polishing, it fits the proof plate to 2 rings or less. The edges of the rings should be smooth and regular, not wavy or fuzzy — smoothness and regularity shows that the surface of the lens is smooth and regular too.

At this stage, for greatest accuracy, move the lens and proof plate to the bottom of the tester. View the fringes as close to perpendicular to the test surface as accurately as possible. With slow careful strokes, continue the figuring until the bands are practically straight across the proof plate. When this is achieved, the lens is finished.

For best results, have the surfaces coated with an anti-reflection film. Magnesium fluoride is the standard and inexpensive coating; it largely prevents ghosts and reduces light loss.

Centering and Edging

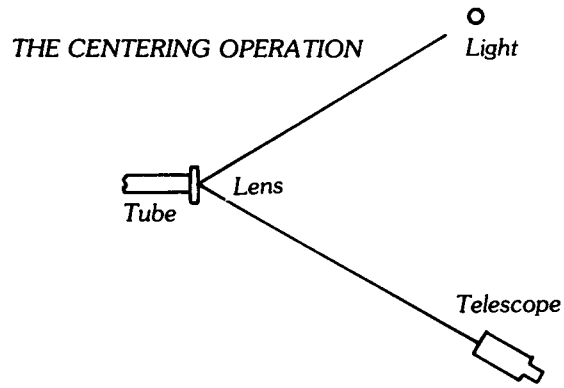
The centering or edging process will be covered in case it is needed. This is a slow and tedious process, so avoid it if you can. If you've made an error in your wedge control, the lens may show color and coma in use. If a check with the wedge test jig shows the lens needs centering to eliminate wedge error, the following process can be used. This process is usually necessary for lenses fabricated from blanks not purchased edged from the supplier but biscuit cut from a rough blank. The method requires a lathe or some type of horizontal spindle. This description applies to a lathe.

Chuck a brass tube about ¾ as large as the lens diameter in the lathe and give it a light truing cut on its O.D., I.D., and edge. Then polish the edge (a piece of felt and polishing compound will do the job) until all traces of scratches are removed.

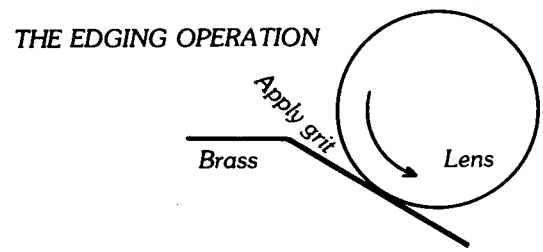
To protect the lens from breaking should it fall off the tube, lay some soft rags on the lathe bed beneath the end of the brass tube.

Warm the tube with an alcohol lamp so that a stick of #9 centering wax melts when touched to the tube. Make a bead of wax all around the end of the tube. (You can get away with using a propane torch to heat the tube, but keep it on its lowest flame to avoid excessive heat.) Heat the lens in warm water, dry it off, and stick it to the end of the brass tube, taking care to position it centrally on the tube. Warm the brass tube and wax, then press the lens firmly down on the tube. You'll see a brass ring touching the glass with wax on both sides if you do it properly.

Turn on the lathe to 50 or 60 r.p.m. Warm the wax and brass, then, with a small, hard wooden stick or rod, center the lens on the spindle. A minimum of shifting will be necessary if you originally attached the lens nearly concentrical. The lens won't be scratched if the brass edge is smooth and has a good polish. For final centering, you'll examine the reflection of a small light source from the front surface of the lens as it rotates



on the lathe head. Solidly mount the light and a small viewing telescope (one equipped with an eyepiece having crosshairs at its focal plane) on the lathe. With the brass and wax just warm enough to permit the lens to be shifted (but not loosen on the tube), rotate the lathe spindle by hand and note if the image of the light is stationary. Adjust the lens and viewing telescope until the image of the light sits stationary as the lathe head is rotated. As a final check, run the lathe and see if the image stays still. If it does, let the wax cool and the first part of the job is done. Now you're going to grind down the edge of the lens until it is round and concentric with the lathe spindle center.



Attach a brass sheet about 0.040" to 0.065" thick to the lathe's cross slide. One portion is bent down at a 30° angle. With the spindle running at 50 to 60 r.p.m., bring the brass up until light contact is made with the glass. Be gentle: if brought up hard against the glass edge, chipping can result. Do it slowly. Feed a mixture of 30μm grit and water onto the brass sheet so it flows between the brass and lens. This will work on the high areas and remove them.

When work has stopped at the first high, slowly feed in the brass until another high spot is worked upon. The brass will wear down and groove; do not let it get too deep or chipping can result. Another danger is that the polished surfaces of the lens will get small concentric scratches on them. Move the brass plate regularly to prevent this.

Once the grinding is taking place all around the surface of the edge, then the lens is mechanically and optically centered! You may want to grind longer to obtain a certain diameter. When that is done, reposition the brass so that each edge can be beveled at 45°, using the same procedure. The lens is finished after you clean it up and send it out for coating.

As you progress in your lens grinding career, you will develop your own methods, as I have. The steps outlined in this article are not the only technique that can be used, but they do work.

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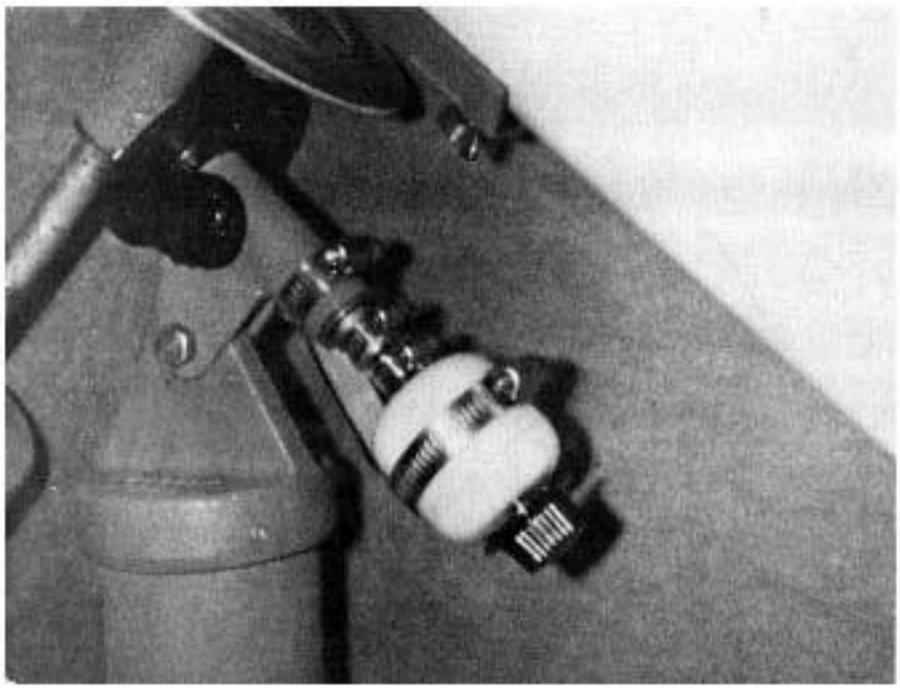
An R.A. Slo-Motion for Small Telescopes



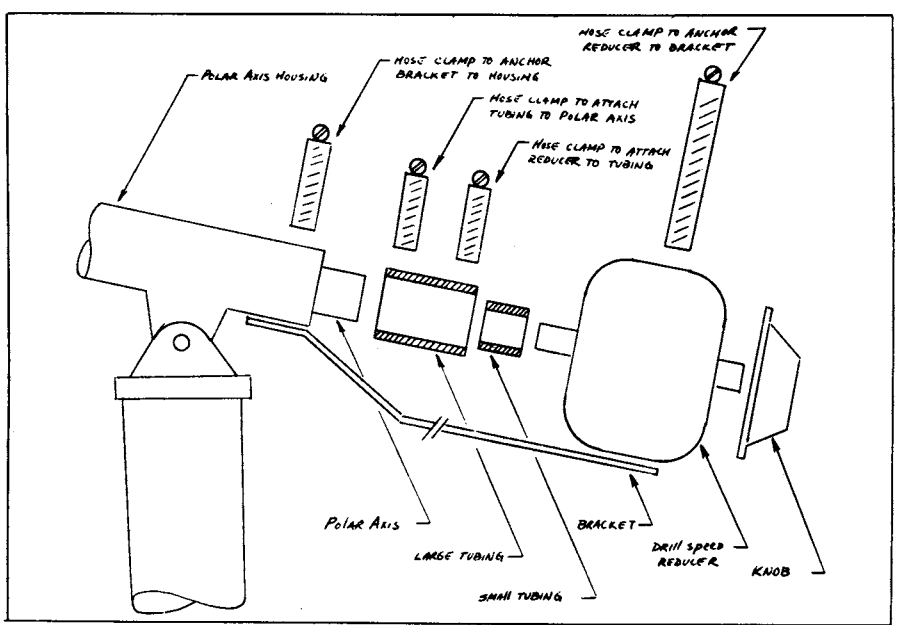
To those of us not involved in astrophotography and not planning to be, an electric clock drive costing from $50 to $70 may be prohibitively expensive. It is, after all, for convenience only.

Rather than resigning yourself to manually moving the telescope tube and the resulting jerky movement, I'd like to pass along a very satisfactory and inexpensive ($5 and $7) method of adding a manual slow motion control for right ascension to any equatorial mount.

Basically, a power drill speed reducer (9:1 or better) is used to rotate the polar axis. All parts can be found at any hardware store. Since equipment and parts will vary, I've omitted giving any dimensions.

A number of variations can be used to couple the reducer onto the polar shaft. My method was to use 2 sizes of clear vinyl tubing. I fit the larger tubing over the polar axis shaft, then built up the diameter of the reducer shaft by fitting a smaller diameter tubing over it. I then slipped that into the other end of the large tube, clamping both ends with radiator hose clamps. The diagram will clarify the idea.

The only item that has to be hand-fashioned for the particular assembly is the bracket to anchor the reducer to the polar axis housing. I used 3/16" aluminum about 1" wide, bent to fit my assembly. But here too, brass, steel, or aluminum mending plates of various sizes can be found at any hardware store and bent to mate with the assembly. Two more hose clamps are required to anchor one end of the bracket to the polar axis housing and the other end to the reducer body.



This method of manual slow motion on right ascension works very well on my 4¼" reflector. The object being viewed can drift far off the field and a half turn of the knob smoothly brings it back in. The control is fast — but not too fast.

A flexible shaft could be used instead of a knob. I find for myself, however, that a large knob gives me better control. By the way, you don't need a clutch. The reducer presents no appreciable drag when manually moving the telescope tube through large changes in right ascension.

Gary Papazian
339 Wood St.
Hopkinton, MA 01748

Cox's Top Ten in Amateur Telescope Making

What are the high points of amateur telescope making and amateur telescope design? Below is my list of the ten most important developments for the ATM — but we'd like to hear from you too. What do you consider to be the big breakthroughs?

1.) The development, in the 1930s, of aluminizing for mirror surfaces.

2.) The invention of the Schmidt camera and its variations for wide-field photography and observing.

3.) The Dall Null Test, which allows paraboloids to be figured without making zonal readings, and also allows figure smoothness to be checked visually.

4.) Electronic control of clock drive motors so that exact sidereal rate drives don't need complex gearing.

5.) The widespread use of achromatic Barlow lenses in observing.

6.) The invention of the Maksutov telescope and its acceptance and fabrication by amateurs.

7.) The Caustic Test for accurate zonal testing of large and fast mirrors.

8.) The development of small electronic calculators that spurred amateur interest in optical design.

9.) The development of TCTs as an outstandingly high quality observing tool for lunar and planetary work.

10.) The application of the catadioptric principle to design high quality telescopes with large mirrors and small correcting lenses. Especially important is the freedom to design systems with spherical optics throughout.

— R. E. C.

What's New?

a listing of new products of interest to telescope makers

Listings in this column in no way constitute an endorsement of any company or product shown. Manufacturers please note that each item will be confined to a brief description and specifications.

Refractor Objective Kits

Kits are available for making lenses of 3" and 4" clear aperture. Includes two fine annealed optical glass blanks (crown and flint), four glass grinding tools, supply of abrasives, polishing compound, pitch, radius templates, test filter, and lens spacing stock. Finished objective is a Frauhofer type airspaced objective developed by N. Remer Optics. Includes twenty pages of instructions covering work from rough grinding through shaping, to testing and figuring. Instructions assume mirror making knowlege.

For more information, write: N. Remer Optics
Box 306
Southampton, PA 18966

Precision Worm Gear Drives

Precision worm gear drives for telescopes in the 6 to 20-inch aperture range. "Our drives are machined to the highest standards resulting in smooth and accurate tracking." Gear train runs at sidereal rate; basic unit includes 2024 T4 aluminum worm gear, phosphor bronze worm, clock spur gear, and motor pinion gear. Also available: motors, worm housings, slip clutches. 7" gear set, $100; 15.8" gear set, $240; other sizes available.

For more information, write: Thomas Mathis
Precision Worm Gear Drives
1806 Curtis Street
Berkeley, CA 94702

BARNESITE® Polishing Agent

Lindsay™ BARNESITE® was the "premier precision polishing compound" until it was discontinued over five years ago. It's back now, and according to the manufacturer, it "has sucessfully completed a six month evaluation program with some of the most critical producers of precision optics."

TRANSELCO Division, Ferro Corp.
For more information, call (315) 536-3357

4¼" RFT Kit

Kit contains tube, finished mirror, diagonal, eyepiece holder, diagonal mirror hub. You supply mirror cell and diagonal hub support. Mount not included. With 16 pgs. of instructions.
$27.50 ppd; eyepiece $11.95.

4¼" Lunar-Planetary Scope Kit

Kit contains 55" tube, finished f/12 mirror, diagonal, diagonal mirror hub, drawtube focusser. You supply mirror cell, hub support. Mount not included. With assembly instructions.
$39.95 ppd.

Portable RFT

4¼" f/3.5 paraboloidal primary, aluminum alloy construction, black and clear anodized finish, fast color-dot system for various modes of use. Three eyepieces — 14x, 30x, and 60x. Range of focus down to 3 feet; attach camera with adaptors (not included). Dust shields, instructions. With case, $169.95

Coulter Optical Company
Box K
Idyllwild, CA 92349

A Solar Cooker

A low-priced solar cooker made from foil-lined cardboard cooks hot dogs, hamburgers in 12 to 18 minutes. Food is wrapped in "solar foil"; curve of the cooker directs the rays of the Sun to the food. "What a way to beat the energy crisis!" says manufacturer. Unit is portable; take it camping, fishing, etc.
$6.99 plus $2.00 postage; $2.25 for package of extra solar foil.

Leisure Amusement Company
227 E. Sunshine
Springfield, MO 65807

DEEP-SKY OBSERVERS!

GET MORE OUT OF YOUR OBSERVING!

DEEP SKY MONTHLY is a magazine for deep-sky observers and is the only publication of its kind. Each month several clusters, nebulae, and galaxies are reviewed in depth, including a sketch representing the precise view of an object through a common telescope. Feature articles cover observing techniques, history, objects, and other topics. A staff of experienced writers including Richard Wilds, Gerry Lafontaine, Alan Goldstein, and Chesley Runyon report the objects to you while Jamey Jenkins covers photographic techniques and Glenn Chaple surveys the month's prospects for double stars. Astrophotographs are published from the leading amateurs including Jack Newton, Martin Germano, Howard Zeh, Dave Healy, Ben Mayer, K.A. Brownlee, Walt Hamler, Dr. Hans Vehrenberg, John Sanford, and S.J. Warkoczewski. Occasionally photographs from Hale Observatories are published, as well as observations by our readers. **DEEP SKY MONTHLY** is a great complement to deep-sky observing and lets observers communicate their thoughts and ideas to others in the field. Order a subscription today - it will open new worlds to your deep-sky observing. Subscription prices are: $5.50 per year in USA; $7.00 in Canada and Mexico; and $9.00 in Europe.

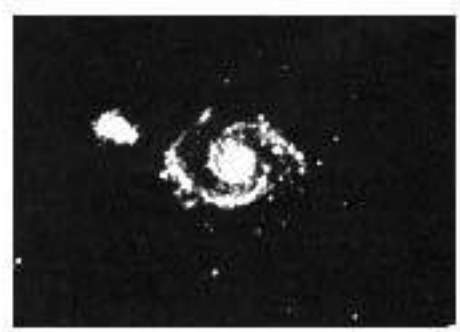


photo by Jack Newton

DEEP SKY MONTHLY, INC.
A Non-Profit Corporation of Deep-Sky Astronomers
104 Oakhill Drive, Oxford, Ohio 45056
Dave Eicher, Editor Telephone (513) 523-5554

Letters (con't)

Chretien. However, I imagine that the hyperbolic figures are much more difficult to attain than the parabola, which I found difficult enough.

Realizing this, and the elegance of the all-spherical (or nearly so) telescopes, I wonder if you might consider an article on the use of smaller elements on large telescopes to correct such bugaboos as spherical aberration (a la Buchroeder's spherical relay telescope). I know that an article on this would be very helpful to truly large telescope building.

Timothy D. Van Orden
12 White Street
Holley, NY 14470

Dear Mr. Van Orden / Thanks for pointing out the error. I'm glad to see that people are reading this article closely and applying it.

The primary R-C hyperboloid should not be too difficult; it's only several percent deeper than a paraboloid. The secondary, I would think, would be quite difficult, especially because it's a convex surface.

You'll notice an article on a big all-spherical system in this issue of TM. While lenses seem like an awful lot of work, so does parabolizing a big mirror. With all-spherical systems, you have the enormous advantage of knowing — via Foucault test — that every surface is perfect. Of course, if you've mastered the art of big paraboloids...that's another thing.

—R.L.B.

TMT

Dear Richard / Thanks for doing such a fine job on your first issue of Telescope Making.

I tried to find the William Charles **Telescope Making Techniques** *that you mention in the editorial, but I was unable to secure the address. Can you help?*

Also, if you are looking for material to publish (bet you aren't, however), I have a huge need to build a quality Foucault tester. I don't have a machine shop, but some ATM must have plans, and if you published them, we could all benefit.

Hope the size of your letters column will be larger in future issues of TELESCOPE MAKING. Keep up the good work.

John McLaughlin
7200 Trenton-Healdsburg Rd.
Forestville, CA 95436

Dear John / You and several other people asked for the address of **Telescope Making Techniques (TMT)**. *It is:*

William Charles Communications
P.O. Box 231
Kennelon, NJ 07405

They are a quarterly magazine, but their last issue (#4) came out last fall. They also publish each years' issues as an annual book.

I hope the TMs out there are reading these letters, and that those who have designed and built Foucault testers will send TM5 descriptions of their projects.

—R.L.B.

Macalester's 24½-incher

Dear Sirs / The enclosed 8 x 10 illustrates the status of Macalester College's 24.5" in 1971. The main mirror was in, the scope balanced, but the mirror was NOT coated. The local facilities couldn't at that time handle such a diameter (or didn't want to even if they could, because they were afraid of breakage).

The mirror came out astigmatic. After a year or so of testing, we found the astigmatism could be somewhat compensated for with a +/- cross cylinder ophthalmic lens which I had a local lab grind for me. It was a +.25/-.50 axis, rotatable to fit the demand. When inserted into the final focal cone, we could get it to a spot where the plus aspect shortened the f.l. and the minus factor lengthened the f.l. so that the cylindrical distortion was just about compensated for. But the big question remained: should we leave it as it was, have it aluminized, and work with correcting lenses of varying power until we hit it right on the schnoz, or should we try to correct the astigmatism of the surface. We reasoned out what part of the surface had to be selectively deepened. (It's easy to understand when you see the interval of Sturm as a two line focus from a bright grain of wheat lamp.) The interval is then measurable and can be translated to a f.l. or radius difference. Work began, with rather amazing improvement, in spite of previous advice to "seek out nearest hard hydrant and hurl mirror at same!"

But time closed in, badly. Classes grew in size — practice ditto. Demands on home front time also increased what with constant remodeling of a 60-year-old duplex. So the big mirror is still on the polishing machine table and the tube sits in its down position getting in the way of those using the 6" refractor (left foreground) or the 12" Cass. (to immediate left). That 16" in left background is now a Cass. system also ... M-13 last night filled up the field ... spectacular.

The north pier is the wall of the observatory itself. That bracket was an interesting welding challenge, but I got it together o.k. The axis itself simply rests in a Teflon half shell; no need for a 360° enclosure. There are adjustments built in for our final axis setting, but it didn't need much. Several drive designs were worked out on paper; none have been built as yet. The best bet, we feel, is the driven nut with tape wound around a good sized drive wheel with the clutching being in the tape-wheel interface itself. This sure beats trying to buy expensive 360-tooth worm wheels and gears and then having only one face-to-face contact anyway.

There is now rust on the polar axis shaft so in order to rejuvenate the project, the whole thing has to be taken down and reworked. The south support is a heavy 45° pipe flange fitting into which are fitted aircraft engine bearings obtained on the surplus market in the 40s. Shafts are steel piping of 4" size, very rigid. The declination axis goes right through the tube, through the light path ... HORRORS ... think of all the diffraction! Tsch! But the structural support it offers more than offsets some theoretical upset of imagery.

That tube is a heavy Sonotube, 30 inches O.D., with quite an array of internal supports blending with the Dec. axis structure. Oak and maple are used in heavy quantities and no joints have loosened up — as yet anyway.

Sherman Schultz, Director
Observatory - Planetarium
Macalester College
St. Paul, MN 55105

■